The Journal
Hyderabad Geological Survey

Vol. II. Part 2

Water-Supply Paper No. I. Geology of the Underground Water Resources of the Hyderabad State and Notes on Well Sinking

BY

CAPT. LEONARD MUNN, O.B.E. (MIL.); M.E. (CAMBORNE); F.R.A.I., F.R.S.A.

Special Officer i/c Well Sinking Department and Geological Survey.
H.E.H. The Nizam's Government

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PREFACE

IT has been rightly said that " Life is an aquatic problem." In Hyderabad State, whose revenue is nearly wholly dependent on agriculture, with a climate practically rainless for five or six months out of the twelve, there are few Mulkis who are not sometime or another interested in the question of underground water-supply. I, therefore, feel that no apology is needed for attempting to describe the mode of occurrence of water in the rocks of Hyderabad State, in the hopes, that it may assist those in search of this vital necessity to life and comfort.

The main object I have had in mind while writing this pamphlet is to endeavour to make it intelligible and useful to the average reader and the pamphlet is not intended for the trained geologist, to whom most of the facts will be already known. Keeping this in view, in every case where technical words are used the explanation is given, thus saving the bother of referring to a glossary.

Wherever possible, I have attempted to obtain my examples from localities within the State, but this has not always been possible. For the sake of space, I have been compelled to make statements in a somewhat generalised manner, without the due qualifications which would be found in larger works.

Throughout, generally in the text, I have acknowledged the many authors to whom I am indebted and at the end of each chapter will be found a further list of references. Writing in the jungle away from a good Library makes these references limited but, I hope, adequate.

It is hoped to make this the first of a series of Papers on this most important subject. The value of the Series will be greatly enhanced if officials and others will only kindly supply the author with the data asked for at various places in the text.

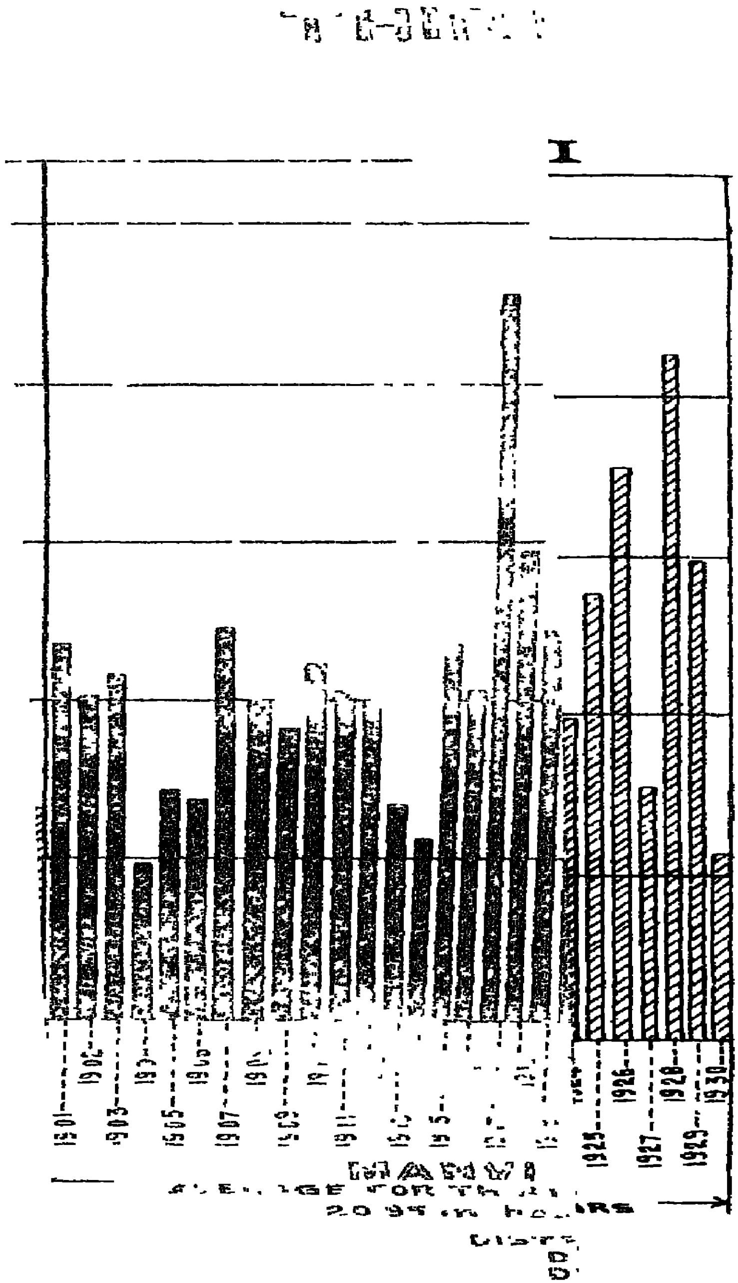
Finally, I have to thank all the members of my Geological Staff for their able assistance and Mr. P.F. Durand of the Jagirdars College, Begumpett; Mr. M. D. Gadgil, Asst. Chief Engineer, H.E.H. the Nizam's P.W.D., and Mr. T. C. Worth, for very kindly looking over and correcting the draft. and Dr. Mahadevan for preparing the Index.

LINGSUGUR, L. M.
2nd September 1933.

however, because at first they come out of Arabia and are too dry. Early in June there is a radical change; the air which reaches India now comes from the southern Indian Ocean, and after travelling for 4,000 miles over the sea it is heavily charged with water vapour. It is this water vapour which provides the rainfall of the Indian monsoon Since the rain is by far the most important economic factor in the life of India, making all the difference between sufficiency and famine, it is the rain rather than the wind which is popularly termed the "south-west monsoon," or even simply "the monsoon." In this sense the monsoon begins in Ceylon in the last week of May, in Bombay about June 5th, in Calcutta a week later, and in the north-west not until nearly the end of June.

"The wind does not maintain its south-westerly direction over the whole of India. The western coast from Bombay to Malabar has steady west-south-west winds, which bring very high rainfall to the lofty Western Ghats—more than 120 inches in many districts—but in the Bay of Bengal the wind becomes southerly. Part of the moist air crosses the Khasi hills of Assam and gives Cherrapunji its annual deluge, but most of it is deflected westwards by the lofty barrier of the Himalayas. Dr. G. C. Simpson has compared this part of India to a box with two mountainous sides which are almost everywhere more than 6,000 feet high. The air rises over India not because it is hot and therefore relatively light, for in fact it is not so hot in July as it is in May, but because the general pressure distribution over Asia and the Indian Ocean forces it into this box or cul-de-sac, out of which it can only find a way by rising over the sides. The Indian monsoon results from several causes, from Summer heat and low pressure over the interior of Asia, caused by the distribution of land and sea, from the trade winds of the South Indian Ocean, which are part of the general circulation of the globe, from the earth's rotation, which arranges that the winds blowing from the high pressure to the low pressure shall follow a devious route and arrive heavily charged with moisture, and from the mountain structure of India, which ensures that these winds shall rise high enough to condense their moisture into rain."

The *first* south-west monsoon laden with moisture, derived from its passage over the Indian Ocean, first meets the elevated superheated Ghats which bound the Malabar and Konkan coast and would seem to pass over the south-western and western areas of the State, so that those areas only receive sporadic and curiously local patchy rainfall, which sometimes is entirely withheld. The following areas of insecure rainfall are classified by the Revenue Department as Famine Areas. Raichur District, Surapur Divi-


1901
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sion; parts of Gulbarga Division; Osmanabad, Parenda, Kalam and Latur Taluqs; and Bhir, Ashti and Patoda Taluqs of the Aurangabad Subah; and parts of Nalgonda District. From the examination of the isohyetal map which is printed to superimpose the Geological Map, it will be seen that the first south-west monsoon mostly affects the Aurungabad and Nizamabad Districts, and that it most copiously precipitates on the forested areas of Asifabad and eastern Warangal Districts. This precipitation is especially marked along the forested hills which bound the Pranhita and Godavary valleys.

The real effective monsoon of the Raichur District begins relatively late, generally in the month of August, due to the north-east monsoon which, at this period, commences in the foothills of the north-east Himalayas. If this current fails, Raichur District suffers from drought and bad famine conditions ensue.

It seems, from observation from different parts of the world, that a periodic variation in the rainfall and consequently in the underground water-supply may often take place. Advancing regional desiccation due to climatic changes is difficult to establish, but the desiccation of a given area may be due, amongst other causes, to a diminution of rainfall over the area ranging over long successive years of drought. But a proof of the continuous diminution of the water-table seems often to be contradicted by some successive periods of excessive rains, which appear to upset the general theory. Thus an average level of the underground water-table is likely to be maintained over a long period under equable conditions, but the general tendency of the water-table over the same period of years is to shrink. By studying rainfall figures of the Raichur-Doab for the last 30 years, it appears, that there is an alternating decade in which greater or lesser quantity of rainfall seems to have occurred in the zone (vide: Rainfall Graph Plate I).* However it is realized that 30 years is too short a period

* For further discussion on rainfall of the Raichur District see Appendix III, page 167.

on which to base any definite conclusions. But, history points to a great total shrinkage of the water-table which has occurred in the last 200 years in the south-western, western and central portions of the Hyderabad State.

In 1931 (1340 F.) the summer water-levels of the wells in the western part of the Raichur District were taken, and a tabulated statement has been prepared from the measurements obtained from 1,444 wells. This gives the relation of the ground surface with the underlying water-table, with certain reservations. These sections have been published in the Annual Report of the Well Sinking Department for 1340 F. to which the reader is referred.

No systematic survey of the water-table conditions of the whole State has so far been made; and very little is known of the general underground water-supply problems that frequently arise. The preparation of such returns could easily be arranged for by the Revenue Officials with the aid of the Local Fund Staff and the Statistical Department. The information is badly needed.

Deforestation and its effects on water resources.

Forests have a great influence on the climate and the water resources of any country. This has been universally recognised in all parts of the world and especially in the tropics.

It has been rightly said that, whereas forests on hills affect the rainfall, the forests in valleys is the result of rainfall. All available evidence tends to show that, under certain special conditions, forests may be a contributory factor in causing local precipitation of rain, but only in conjunction with other much more powerful factors. (Dixey). But deforestation and removal of natural vegetation has a far greater effect than that indicated by the alteration of the mean average rainfall, which may not appear to be appreciably altered. Even though the average rainfall does not appreciably change over a long period of years the amount of water absorbed by the soil in deforested areas will be continually decreasing.

Forest and vegetation hamper the run-off of rain into

the nullahs, thereby increasing the percentage of percolation into the soil and thus replenishing the underground water. Their roots assist in this process, while the shade they give enormously reduces surface evaporation.

Borthwick in his book '*Water*' states that "in spite of the fact that a quarter of the rainfall might be withheld by the forest cover and re-evaporated without reaching the soil, the loss from three-quarters that did reach the soil was five times less (some authorities said six times) than from that which fell on unforested ground, the end result being that more water was retained by the forest-covered soil and allowed to percolate to the deeper layers."

The writer, while fully recognising that it is impossible to keep the entire State under forest, is of the opinion that the destruction of forests, and especially the entire removal of all trees and vegetation over large areas in the State, with no attempt or scheme for replantation, has already had a very serious effect on the underground water resources. Early steps should be taken to give cultivators every inducement to remedy this error, and tree planting on a big scale in famine areas, especially along lines parallel to the contours, is most strongly recommended. This will not only assist the underground water resources, but act as a part prevention to the serious soil erosion, which is occurring over large areas.

There is no doubt that the effect of this ruthless eradication of trees, probably combined with a gradual, nearly imperceptible, diminution of the rainfall over long periods will account for the shrinkage of the water-table in the south-western, western and central portions of the State. That this has happened, the history of the Deccan Forts which withstood long sieges, whereas to-day all their wells are dry, alone proves. If further evidence is needed, the reader has but to inspect the wells on the Secunderabad Rifle Range which was once a British Cavalry watering point, or contemplate watering two cavalry regiments and several infantry, besides transport and other units from the wells in Bolarum, to realize what great changes have taken place.

No better evidence can be found of absolute ruthless,

witless destruction of all vegetation, save those trees protected by Government, than a visit to Karimnagar District, east of the new railway line, and south of the Godavary in which the writer lived for 5 years boring for coal. This area was opened for cultivation within the memory of man. Local inhabitants, sixty years of age, have told the writer that as young men, villagers would only travel in parties to Peddapalli owing to the thickness of, and number of tigers and wild beasts in the forest. To-day, save for a few tamarind, mohur, palmyra and toddy trees, protected by Government, the area is treeless, and villagers now delve for roots to obtain fuel. Similar wanton waste must have been practised in the Raichur District, once the dense Dandaka forest of the Ramayana. Here in bygone centuries ancient man hunted *barasingh* stag, the elephant and the wild bison and with the hopes of ensuring good hunting, drew pictures (bruised stone graffiti) of these, on inaccessible boulders and caves, which have been lately discovered by the writer. Here again in the Raichur District the effect of entire destruction of vegetation has been the cause of a serious diminution of the water-table, combined with very serious erosion of the black cotton-soil upon the slopes.

But, in the Asifabad District, where the forest and vegetation now binds together the very sandy soil, formed from the local Gondwana sandstones, if entire eradication of the forest and vegetation is allowed, the writer fears that in certain areas the sand now held in place by the humus and undergrowth will separate from the binding soil and start drifting with the winds, forming shifting sand dunes. Instances of this are already visible in forest clearings. It is certain that these effects are greatly enhanced by the continuous pecking of the surface by herds of goats.

In West Australia, for many years, it was the practice to cut down all the trees in catchment areas of tanks to increase the run-off. This was especially done in the case of the huge water-supply scheme for Kalgoorlie where water is piped from Mundaring Dam, 308 miles away. Here

deforestation led to the most disastrous results, as, afte the destruction of the timber, the increase of sodium an potassium chlorides in the run-off became so high, that th water became unfit for trade, especially the cyanide proces for extraction of gold, for which pure water was especiall needed, and the percentage of salts became so high that i commenced to corrode the pipes.

It may therefore be taken as a certainty that deforesta tion causes a permanent lowering of the undergroun water-level and leads to most serious diminution of th underground water resources of a country, especially in th tropics. An early effect of the destruction of all vegetatio is the development of gullies, or washaways on hillside and plains, the former being very noticeable along th scarps of the Deccan Trap* plateaux in the Marathwar country, the latter on all black cotton-soil slopes. Thes gullies are the active agents for the annual removal of tons o soil from the affected areas.

I have to thank Nawab Hamid Yar Jung Bahadur Inspector-General of Forests, for bringin the following facts, taken from "*Forests an Streams*" by Dr. Rodway, to my notice.

Efficacy of re-plantation

The best evidence obtainable of the result of excessiv felling of trees and ravages of goats, comes from the islan of St. Helena. This island situated in the South Atlanti in the middle of the south-east trade winds, is ideall placed to receive ample rainfall. Owing to cause mentioned above, the rainfall became so diminished tha serious droughts occurred which occasioned great losse of cattle and crops. Towards the close of the last centur strenuous steps were made to restore vegetation, with th result that in late years the rainfall on the island has bee much improved.

The history of the islands of Mauritius and Madeir both tell the same tale. Destruction of forests and vege tation were at once accompanied by serious droughts—

* From Scandinavian *trappa* a step, describing how these lava flow weather.

change of climate—and it was only after intensive replantation that the rainfall returned. The island of Curacao, once beautiful with gardens and plantations, is now owing to the same cause, an arid waste, though the dense forests of the South American continent are but sixty miles away. With all these facts before us it would seem a necessary line of practical politics for His Exalted Highness the Nizam's Government to institute, at once, a well considered Scheme of replantation in all the Famine Areas.

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PART II

UNDERGROUND WATER-SUPPLY

Introduction.

FROM a water-bearing point of view the surface crust of the earth may be divided into two types, namely the soil and the rocks, the soil being derived from the rocks. The rocks may be regarded either as consolidated sediments derived from igneous rocks, or, igneous rocks themselves, out of which the sediments were formed and subsequently consolidated. The soil, therefore, may not only lie upon the igneous rocks, but, also upon the consolidated sediments, as well as on both.

Soils.

Soil is the intermixture of rock-flour in a finely pulverised state in which organic matter is also included.

Just as sedimentary rocks are detrital accumulations formed from pre-existing igneous, or other earlier sedimentary rock masses, so soils can again be divided into two kinds with regard to their origin, *i.e.*, *sedentary* and *transported*. The sedentary soil is that portion of the rock which has been disintegrated and decomposed from the parent rock. It generally occurs as an incrusting layer of crumbling material on the rock from which it has been formed by weathering agencies, and passes by imperceptible gradations of decomposition into the parent rock. These lower gradations of decomposition are called the *subsoil*.

Transported soil on the other hand, although originally derived in a similar manner, has, subsequent to its formation, been carried by water on to the top forming a mantle to some foreign rock to which it has no genetic relationship. The best local typical instance of this is the vast expanses of black cotton-soil in the Marathwara districts of this State. This very extensive soil mantle, no doubt in the main, was derived from the weathering of the slopes of the plateaux

of Deccan Trap and was washed into the valleys below, carved out of similar rocks. However, a considerable portion was carried further afield by the action of wind and water and is now found covering many different types of rocks from which it has received little or no contribution.

Rocks.

The term *rock* is used to mean an aggregate of minerals held firmly together either by some cementing material, or by the initial cohesion of the minerals of which they are composed. Thus we have, broadly speaking, two main types of rock. Examined from their genetic point of view, these may be *sedimentary*, or *igneous* in origin. The sedimentary formations may be traced to their original parentage in the igneous rocks. They were formed by water, or sub-aerial action, and subsequently deposited in beds in the bottom of seas, estuaries, lakes, etc., out of which, owing to subsequent earth movements, they have emerged again to form new land masses.

We thus find boulders, conglomerates, gravel beds, sandstones, shales and limestones, all indicating some particular phase of water action and deposition under water. The various sedimentary rocks by their structure indicate different circumstances of deposition. Fossiliferous limestone formations indicate marine conditions, shale and sandstones were deposited in shallow water, either fresh or saline, which can be discovered from their fossil contents, whilst, on the other hand, boulders and gravels indicate sub-aerial conditions. This is a broad generalisation and, like all generalisations, has its exceptions, but the above represents the leading factors of their origin.

Igneous rocks are formed from the primary constituents of the earth's nucleus and their origin is intimately connected with the final consolidation of the earth from its once nebular or gaseous condition. But this aspect of the earth's history touches upon the physical and astronomical sciences. As the writer is here particularly concerned in indicating a broad outline on potential sources of underground water-bearing conditions of soils and rocks, this aspect of Geology need not detain us.

Sources of Underground Water

Origin of underground water.

Lindgren in his '*Mineral Deposits*' clearly states there is no physical or chemical criterion by which the origin of a given water can be determined. A pure water might possibly rise from interior sources and acquire saline constituents during the ascent, and water of superficial derivation might be conceived to have become charged with mineral products. If it is possible to distinguish between waters derived from the surface and those brought up from the interior of the earth, the evidence must be circumstantial and depend on geologic and pysiographic testimony, such as geologic structure, igneous history, rainfall and drainage basins.

The water found in rocks can, therefore, be divided under two heads.

1. *Meteoric Waters.*—(*a*) This is the water derived from rain which has simply descended into the earth and is stored in cavities, fissures, capillary openings, either to ascend at suitable places under hydrostatic conditions, or remain stored in the rocks.

(*b*) Some water is stored in sedimentary rocks at the time of their deposition. Such water has been termed "*connate*" but is really meteoric in origin and need not bother us further.

2. *Magmatic, or Juvenile Waters.*—A third part of underground water is derived from deep-seated sources beneath the earth's crust. Schuchert, the great authority on Historical Geology, believes the first primeval sea, which he terms Archeozoic, contained only about half the volume of the existing oceans, the rest having been formed during geological times. It is calculated that the Carlsbad spring alone which discharges two million gallons a day would in five hundred million years have raised the sea-level by one hundred and sixty feet. The driving of the Simplon Tunnel, and the evidence derived from deep mining go to prove the existence of magmatic water.

Rainfall is dispersed by three different methods, *evaporation*, *run-off* by nullahs and rivers to the sea, and thirdly by *percolation* beneath the surface to swell the earth's underground water-supply. A moment's consideration will show, that such an enormous amount of different factors here come into play, that no formula defining the proportions in which these three processes, *viz*. evaporation, run-off and percolation may act can be devised. In India, where surface storage of water has been the subject of the greatest investigation, evaporation and run-off has been studied in various localities, but a general formula has been considered sufficient in most irrigation projects. No investigation has yet been undertaken on the percolation of rainfall and its effect on recharge of the water-table.

Disposal of rainfall.

Obviously many factors come into play in dealing with this calculation.

Evaporation.

The loss by evaporation from rainfall comes under the following heads :

(*a*) Evaporation from water surfaces.
(*b*) Evaporation from the soil.
(*c*) Transpiration by vegetation.

Mr. C. C. Paul gives the loss in a Reservoir by evaporation in decimals of a foot, which, for the purposes of this pamphlet, has been reduced to inches.

TABLE I.

Month			*Feet*	*Inches*
January ..	..	..	·41	4·92
February ..	..	..	·37	4·44
March ..	..	..	·45	5·40
April ..	..	..	·50	6·00
May ..	..	..	·64	7·68
June ..	..	..	·50	6·00
July ..	..	..	·57	6·84
August ..	..	..	·56	6·72
September	..	..	·64	7·68
October ..	..	..	·47	5·64
November ..	..	..	·46	5·52
December	..	..	·23	2·76
	Total	..	5·80	69·60

These figures are for evaporation of a big surface of water, but the problem of evaporation of rainfall brings in other factors which are impossible of accurate determination.

The evaporation of a small shower of rain falling on a heated surface of soil or rock will be very high ; but, if two or three inches of rain fell on soils or rocks of like temperature, the total evaporation would apparently, even then, be higher than the evaporation on an open sheet of water. Owing to the fact that the total absorption of rains by soils can only be roughly estimated by the subtraction of that factor, plus run-off, from the total rainfall, it is at the best but a crude calculation. In England, we are informed, evaporation amounts from 1/3 to 1/2 of the total rainfall and on the coastal plain of Virginia U. S. A. (Lat. 37°) the evaporation exceeds half the rainfall.

Run-off.

The word run-off is used in two senses. In its quantitative sense it means that portion of the rainfall (as measured at the lowest point of the catchment under observation) which flows away from the watershed by means of nullahs and streams, whether by direct flow, or seepage, or springs. It is then expressed in inches, or in percentage of the rainfall in question. In its qualitative sense it means the rate of flow as measured in the stream at the point of observation. It is then expressed either in terms of inches per hour over the whole catchment, or per sq. mile of the catchment, or in cubic feet per second.

Taking the earth as a whole, the run-off in its quantitative sense is estimated as one-fifth of the total rainfall; but, it is obvious that vegetation, geology, contour and climate are all controlling factors. Run-off may therefore vary from 100 per cent. on a rocky island to nil in the Bikanir desert. For the calculations for the Nizamsagar Project Mr. C. C. Paul, in his able report, has given the following percentages for the run-off in the different districts through which the river Manjra flows before reaching the dam site. The writer has added the geology of each area in the column headed Remarks.

TABLE II.

Name of district	Monsoon Av. over 40 yrs.	Percentage of run-off	Remarks
Bhir	25.77	14.0	Deccan Trap
Osmanabad ..	31.07	21.0	do
Bidar	33.87	23.0	Deccan Trap and areas of laterite
Medak	32.15	21.5	Mostly gneissic country
Nizamabad ..	36.66	33.4	Deccan Trap and gneiss

For the benefit of the country too much stress cannot be laid on the necessity of the various authorities doing their utmost to impound the rainfall not only by big irrigation projects, such as Nizamsagar, but of realizing that the smallest kunta, even a road dam, damming back water which would otherwise run to waste, is of value in augmenting the underground water-supply. The total destruction of trees, and the overstocking of the country, especially with goats, which eat every self-seeded sapling as soon as it sprouts, both form great dangers to the country and should be regulated. The writer has endeavoured to bring this to the notice of His Exalted Highness's Government in his reports on the underground water supplies of the Raichur, Surapur and Osmanabad Districts of the Gulbarga Subah. Allied with the question of regulating the run-off is the question of soil erosion, and the remedy for that is field-bunding combined with tree planting parallel to the slopes. Such a procedure has the effect of inducing greater underground percolation, and, if the State cannot see its way to carry on this practice everywhere, at least it should be instituted on the saline areas of the Raichur District where such work will undoubtedly have most beneficial results.

The greater part of the rainfall may be absorbed into

Soil absorption.

the ground, the quantity thus taken up being sometimes as great as 80 or 95 per cent. This absorption may be directly from the rainfall, or indirectly from the rivers, lakes etc., although in most cases the water in the ground moves towards the streams or other surface reservoirs. Movements in both directions may take place at different points in a river's course, for, in a region of heavy rainfall the sub-surface water will move towards the river, while in an arid sandy country, in another part of the same river, it is more likely to seep from the river into the ground. This latter condition along canals is known to all Irrigation Engineers. The percolation of water from rivers into the surrounding country mainly depends on the speed of the river. Stagnant water deposits clay on its bed and renders the channel water-tight, a flowing stream keeps clay in suspension and its bed porous.

The chief factors that regulate the absorption of rainfall by the ground are (1) surface slope, (2) rate of precipitation (3) air temperature, (4) soil texture, (5) vegetation.

If the slope is steep, the rain runs off before the soil has time to absorb it. Less rain will be absorbed from a heavy thunder shower than from a steady downpour, because, each type of soil has a different rate of absorption and, if the water is supplied faster than it can be taken up, the excess runs off. A high temperature decreases the surface tension of water and hence it can be more rapidly absorbed by the soil pores. Sandy soil soaks up rain more quickly than clayey ground because the pores are bigger.

The texture of the soil must also be taken into account, for whereas mooram will absorb 23 per cent. of its weight of water and freely yields its stored water, black cotton-soil, on the other hand, has a high *imbibition*, or capacity of withholding its absorbed water, so the percentage of available water for wells is negligible. In the areas of deep black cotton-soil only a small percentage of the rainfall reaches the underlying rocks.

The soil experiments, conducted at Rothamstead and other places in England, show that water takes not less than four months to penetrate a cap of soil about 60 ft. thick. Although this estimate cannot be accepted in all cases to be the same, owing to possible difference in natural conditions, still it is reasonable to suppose that in a region of a thick soil cap which is not very sandy, a very appreciable period of time lapses ere the rain water percolates through.

"Between the surface of the ground and the ground water-table, if a thick cap of soil as in the malnads (of the Mysore State), is interposed, a single heavy shower of rain falling on the surface of the ground tends to compress the air contained in the porous holes of the soil cap. This reacts upon the water column below, compresses it in one place and raises the water in places free from this pressure. The water thus being forced up will drain off into the streams if it finds an outlet,"—or will recuperate a well. (Mys. Geol. Sur. Record, Vol. X. p. 82).

Another feature as regards black cotton-soil must be noted. In parts of the Raichur area beneath the black cotton-soil, lies a layer of practically impermeable calcareous substratum, which further prevents the rainfall reaching the underlying rocks. Vegetation delays the run-off and the deep ramification of tree roots assist rain reaching the underground water-table. To summarise the whole question the writer cannot do better than quote from Woodward, on page 51 of his '*The Geology of Water-Supply*':

"The available underground water is that represented by percolation, which would be independent of the water of imbibition, and in the ordinary course of nature would rise above the permanent plane of saturation, and be given out in the form of springs.

"The surface run-off may amount to 1/6 or 1/7 of the rainfall, when the ground is formed of a series of pervious and impervious strata, and much more where the catchment area is formed of dense and impervious rocks.

"The annual discharge or total run-off, which in Britain is estimated at from 1/4 to 1/3 of the rainfall, includes the surface flow and the underground outflow (seepage and springs); but of course the underground flow must vary according to the amount of water pumped.

"Under natural circumstances the amount of evaporation and absorption by vegetation may be rather more than half the rainfall. It is estimated to vary in Britain from 10 to 18 inches, and may be reckoned generally at 14 inches. The amount that may percolate is

estimated at 1/4 or 1/5 of the rainfall. Therefore we may roughly reckon the rainfall to be dispersed as follows :—

Evaporation and absorption by vegetation				..	$\frac{8}{14}$
Surface run-off	..	..	..	..	$\frac{2\frac{1}{2}}{14}$
Percolation	..	..	..	..	$\frac{3\frac{1}{2}}{14}$

"Again, if the mean average rainfall be 30 inches, and we deduct 1/5 for reduction in quantity during the three consecutive dry years, we have 24 inches to deal with. Allowing $3\frac{1}{2}$ inches for run-off and 14" for evaporation and absorption by vegetation, there remain a little over 6 inches for percolation and underground supply."

Water yielding capacity of rocks.

The water yielding capacity of rocks in general is directly dependent on the porosity and permeability of rocks, *i.e.* on the freedom of flow of the underground water ; because upon this condition the yield of wells and the capacity of the underground water storage entirely depends. This is directly connected with the capability of the soil and rocks to allow transit of water through their media.

Water-bearing rocks which yield supplies of water are of two kinds :—

a. Porous or pervious rocks which hold water throughout their mass in pore spaces.

b. Rocks in themselves practically impervious in mass, but holding water in joints, cleavage planes, fissures and other openings such as faults or shattered belts.

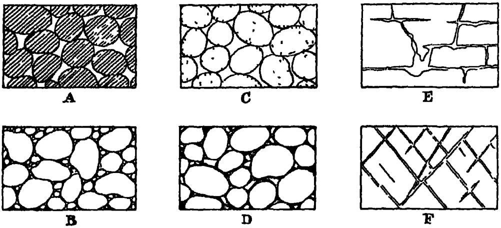

FIG. 1.—Diagram showing several types of rock interstices and the

relation of rock texture to porosity. (After O. E. Meinzer)

A, well-sorted sedimentary deposit having high porosity; B, poorly sorted sedimentary deposit having low porosity; C, well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has very high porosity; D, well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; E, rock rendered porous by solution; F, rock rendered porous by fracturing.

(*a*) *Porosity.*—The capacity of a soil or rock to absorb water is a measure of its porosity. This is usually expressed as a percentage of its entire volume. For example, if 100 cft. of sandstone can absorb 20 cft. of water, the rock is said to possess a porosity of 20 per cent. The porosity and the average amount of water absorbed by a cubic foot of various kinds of material are given in the table below.

TABLE III.

(U. S. Geol. Sur. Water Supply Paper 232. p. 46.)

	Per cent of pore space	*No. of quarts of water absorbed per cft.*
Sandstone ..	4.81 minimum 28.28 maximum	2 to 6
Limestone ..	.14 minimum 13.36 maximum	1 to 5
Marble ..	.184 minimum 3.578 maximum	
Granite ..	.969	1/100 to 1/4
Slate ..	.099 minimum	
Chalk	.304 maximum	4 to 8
Sand ..	33.30	8 to 10
Clay ..	52	0 to 12
Soil	50	12

(*b*) *Permeability.*—The permeability of a rock is its capacity for allowing the entrance and passage of water. Permeable or pervious rocks allow water both to enter and drain away quickly and thus wells sunk in them may yield large supplies.

In an unconsolidated material such as soil, alluvium, weathered rocks, etc., circulation of water mainly takes place through pores. Soils are highly porous having a porosity of about 50 per cent. but they are frequently too shallow to serve as potential storage reservoirs. Often, soils do not extend down even to the upper limits of the saturation zone, however, they are most important as being the conduit by which a portion of the rainfall they have absorbed is transmitted down to the zone of saturation.

Interstitial pores (1) in unconsolidated material and their relation to percolating water.

Although the pores in weathered rock may be ordinarily small, all weathered rocks are not equally porous, nor is the capacity to hold water the same. The yielding capacity of this retained water also varies. Thus for instance, clay and sand may be compared. Generally, the porosity of sand is about 40 per cent. but it freely yields a very large proportion of its water which passes through the pores so that a large amount becomes available. In the case of fine clay however it is entirely different. Although the capacity of clay to absorb water is about 50 per cent., its yield is negligible. Most of the water absorbed in it is not transmitted and the water thus taken in, is not available. A highly clayey soil and beds of clay, in point of porosity, have much less permeability and do not therefore favour the downward percolation of rain water.

Sandstones, a consolidated bed of sand and also limestone, which are all compact and solid absorb more or less water, but do not transmit the absorbed water freely through the mass, the water being held in the pores of the rock by capillary attraction and the water is given up very slowly.

Interstitial pores (2) in consolidated rocks.

Pure shale, no doubt, contains a large amount of absorbed water but has such small pores that water is held very tenaciously with little or no transmission. An examination of Fig. 6 page 36 will show how such rocks, owing to their impermeability when acting as confining mediums of highly porous strata, under certain conditions

may form reservoirs of underground water of vast importance. The igneous rocks like granite and metamorphic rocks like gneiss are composed of crystals closely interlocked with one another and hence there is little pore-space in them. Fuller* states that granite will, on the average, hold about ·3 quart of water per cubic foot in the spaces between its grains. Within a radius of 500 ft., around a well 300 ft. deep, the quantity of water stored would approximately be 17,600,000 gallons, but the pore spaces are so small that hardly a drop of this would be yielded to the well, that which is obtained only coming from joints and fissures, etc. This statement is substantially true of all the crystalline rocks.

When the pores in rocks such as sandstones and weathered rocks are very small, the interstitial circulation through these pores is also correspondingly slow. This slowness, however, has a very beneficial effect on the uniform flow of springs and wells throughout the whole year.

Water yielding capacity. Specific yield.

Some authors refer to this quality in rocks as *specific yield*. It is the amount of water in any rock which forms an available supply if pierced by a well or bore-hole.

The writer can find no table giving any details.

The following table gives a general idea of the qualities of rocks in the State. Imbibition in this table means the capacity of a rock of withholding its absorbed water.

* Fuller, U. S. W. S. P. No. 319. 1908.

TABLE IV.

Rock	Water Storage	Permeability	Imbibition	Specific yield
Granite* ..	Very Low	Very Low	High	Negligible*
Gneiss*	do	do	do	do *
Schists*	do	do	do	do *
Limestones ..	Low	Low	Very High	do *
Coarse sandstones ..	High	High	Low	High
Fine sandstones ..	Medium	High	Low	Moderate
Shales	Large	Low	Very High	Negligible
Conglomerates ..	Very High	Very High	Very Low	Very High
Gravels and Boulder Beds	Very High	Very High	Very low	Very High
Deccan Trap.				
Fine grained Basaltic.*	Very Low	Very Low	High	Negligible*
†Vesicular and Amygdaloidal ..	High	High	Low	High
Decomposed Dn. Trap layers and ash beds	Very High	High	Low	High
Laterite ..	High	High	Low	High

It must be carefully noted that available percentage in these rocks marked * is given in respect to the rock itself and takes no account of water contained and available in joints and fissures, which may be very high.

† Vesicular Trap with spongy appearance. Amygdaloidal, almond shaped holes often filled with secondary minerals. Holes due to escaping gases.

Movement of water in soil.

Under interstitial spaces, the porosity of shallow soils has been considered, and it has been noted that in such cases they only act as a filtering but not as a storage medium.

In cases of great depths of soil the rain water sinks through pores and interspaces and, if the soil rests on a

more impermeable substratum, this great depth of soil may hold a large accumulation of water. Although the surface configuration may appear practically level, yet the underlying rocks may form a huge basin, the periphery of which may or may not be concealed. Such instances may be discovered by chance, or their existence suggested by outcrops. These basins frequently form very important underground reservoirs of water, see Fig. 11, page 72. The following table V, showing rate of percolation of water in different kinds of soils, is taken from United States Geological Survey Water-supply Paper 219, page 27.

TABLE V.

Kind of soil	Diameter of soil grain in inches	Velocity with gradient of 100 ft. per mile	
		Feet per year	Feet per month
Silt ..	·00012 or 1/800 nearly	12	1 ft.
Very fine sand ..	·0028 or 1/350 do	66	$5\frac{1}{2}$ ft.
Fine sand ..	·0060 or 1/160 do	304	1 ft. per day nearly.
Medium sand ..	·0140 or 1/70 do	1,650	5 ft. do
Coarse sand ..	·0600 or 1/33 do	7,577	22 ft. do
Fine gravel ..	·1200 or 1/8 do	121,229	33 ft. do

Movement of water in igneous and metamorphic rocks and consolidated sediments.

In the igneous rocks, however, the effective waterways are the joints, cracks, fissures etc., which open passages for percolation sufficient to be of considerable value as a source of supply. The water usually follows the dip or inclination of these joints which may be vertical, transverse or horizontal.

In the gneisses and schists generally, the more or less vertical fissures are the most effective openings. In granites

the horizontal fissures are also useful in keeping up a communication in the circulating system. In the sedimentary bedded rocks, the horizontal bedding planes also play a prominent role, particularly when the pervious and impervious layers intervene. As the water descends underground both in igneous and sedimentary rocks, these selective fissures become less and less in size and frequency and are finally reduced to their minimum capacity. As a general effect the flow of water in the upper zone is high but becomes less and less as depth is attained.

Moreover, the flow of water in these superficial openings is directly proportional to the weathering of the rocks into which the passages intertwine. The surface water charged with carbon dioxide (CO_2) and humic acids derived from vegetable decomposition, forms a very powerful solvent and so the vertical joints are likely to be more widely affected than the other joints, either transverse or horizontal, the latter being affected the least. In the intersection of joints, however, the horizontal percolation may be greatly increased as the water gets easy access to them during its downward filtration.

Effects of weathering in pores and openings.

The igneous lava outflows known as Deccan Trap have been dealt with on pages 89-92. Suffice here to say, that, although the horizontal joints frequently give fair supplies of water, the main valuable potential supplies are to be struck in the highly porous layers which consist of heavily weathered Trap flows.

The nature of openings in rocks may be briefly noted here. These may be divided into two classes in accordance with form, or size. Thus, classifying by form, three phases may be distinguished:—(1) Those openings which are of great length and depth as compared with width: this class is represented by fissures, faults, joints, divisional planes etc. (2) Those showing tubular openings: these latter generally occur in mechanical sediments, *e.g.* conglomerates, sandstones etc. (3) Those showing irregular

Openings in rocks.

openings, such as vesicular lavas and irregular fractures in rocks typify this form.

In classifying by size, three phases may likewise be distinguished :—(1) *Super-capillary* openings ; (2) *Capillary* openings ; (3) *Sub-capillary* openings. The super-capillary openings include a great number of openings formed by earth movements, resulting in faults, joints, bedding planes, partings and the openings between the laminæ in highly fissile rocks. They may also be circular tubes exceeding ·508 mm. in diameter, and about ·254 mm. width in sheet-like openings. In the openings of super-capillary capacity, the ordinary laws of hydrostatics apply. A large majority of the rocks of this State belongs to this class.

Everyone knows that rocks are not continuous structures forming one solid mass of indefinite extent. They are split up by planes of division of various kinds which break them up into well-defined masses. The commonest of these planes are known as joints, and may be examined in any outcrop or quarry. Another important set of divisional planes are produced by earth movements and these lead to *cleavage* and *foliation*. Such structures are characteristic of metamorphic rocks such as crystalline schists and gneisses both of which occupy big areas in the State. See Photo Plate I, figs. 2 & 3.

Cleavage is the property of splitting along parallel planes and is best exhibited in slate, and is well illustrated in Shahabad stone quarries. See Photo Plate I, fig., 4. Foliation consists of parallel arrangement of the minerals of the rock and this parallel arrangement often allows the rock to split more easily in one direction than in any other. Gneisses are always more or less foliated and it is this characteristic which allows the *waddar** to burn off slabs from its surface. Cleavage and foliation differ from jointing in that they admit of only one direction of fissuring instead of three. Since, however, the fissures may be, and usually are, much more closely placed, and

*For meaning of the term see foot-note on page 155.

are almost always highly inclined to the surface of the ground, cleavage and foliation planes are often more effective than joints in permitting the percolation of rain-water and converting what would, otherwise, be an impervious rock into rock of high water-bearing potentiality. Neither cleavage nor foliation produces actual divisional planes in a rock. They only produce a tendency to split, which weathering subsequently converts into actual fissures. In capillary openings, the openings vary between ·06 mm. and ·0002 mm. in diameter in circular tubes, and ·25 and ·0001 mm. in sheet-like passages. Here the laws of capillary flows apply. Sub-capillary openings are smaller than ·0002 to ·0001 mm. in dimension.

The passage of water through rocks is subject to the laws that regulate its flow through tubes. Tubes that are less than 0·5 mm. in diameter and spaces less than 0·25 mm. wide, are said to be capillary and water creeps along them by *capillary attraction*, and may thus rise against gravity, but it cannot be forced through by pressure of a *head* of water. Larger tubes and spaces are super-capillary, and water is driven through them by gravity and gas pressure. In small tubes, which may be compared to the small fissures and passages in rocks, the flow of water is controlled by friction. This friction in the tube increases directly with (*a*) decrease in diameter, (*b*) increase in length, and (*c*) roughness of the inner surface, and as the square of the velocity.

The slope of a *water-table** depends on the friction. Water poured into an empty U-tube rises to the same level in both arms because the friction is negligible. If the tube be filled with sand, the friction is appreciable, and water poured into one arm rises slowly in the other. If the lower part of the tube be filled with clay, the water only penetrates the clay by surface tension, and the 'head' of the pressure of the water has no effect, and none passes through the clay into the other arm.

* For definition see p. 27 last paragraph.

Piezometer Experiments.

The height to which water rises in rocks may be illustrated by a series of *piezometers* or pressure meters, as illustrated in Fig. 2 taken from Economic Geology by Gregory, page 226.

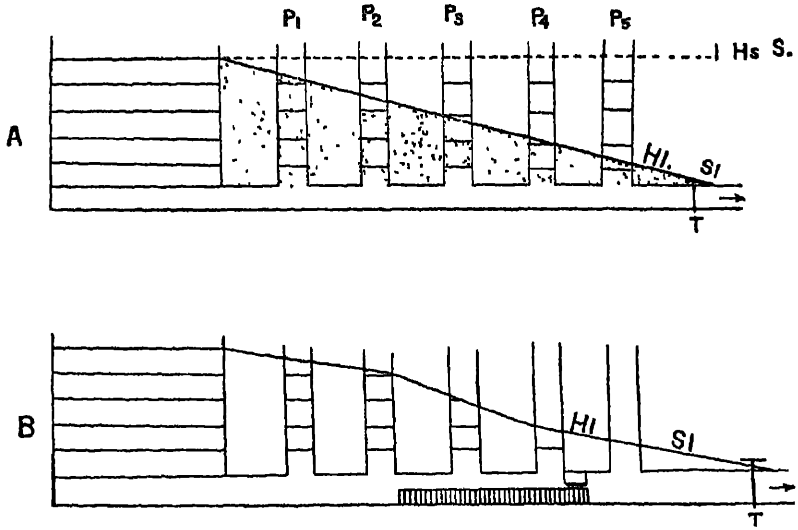

Fig. 2. Water-Level.

Water-level in a series of piezometers P1.-P5. Hs. S—Hydrostatic surface. HI SI—Hydraulic Gradient. (After J. W. Gregory. The Elements of Economic Geology)

"If a horizontal pipe from the lower part of the water tank is closed at the outer end by the tap T and bears a row of vertical tubes (P 1-P 5), the water will rise in each of them to its height in the tank, and that level is the hydrostatic surface (Hs. S). If the tap be opened the water in the vertical tubes falls to a surface sloping from the water-level in the tank to the outlet. As the water is flowing, the conditions are hydraulic, and the inclined surface, HI SI, is the hydraulic slope or gradient. This gradient depends on the velocity of the water along the pipe; the greater its velocity, the lower the water-level in the vertical pipes. The height of the water in each of them is the pressure-head; the difference of pressure-head between flowing and stagnant water is the 'velocity-head' the pressure-head and velocity-head together equal the hydrostatic-head. If the horizontal pipe be constricted (Fig. 2 B) so that the flow of the water along it be reduced, or if part of it be filled with sand so that the friction is

increased, then the pressure-head is raised. The hydraulic gradient therefore varies with the conditions in the outlet channel, and may be an irregular slope. If the pipes and the side of the tank were replaced by a block of porous sandstone the water would soak into the stone and flow through it to an outlet at the free end under conditions similar to that in the pipes. The block of sandstone would behave as a continuous chain of piezometers. If there were no outlet the water would saturate the block to the level of the water in the tank; the water-table would coincide with the hydrostatic surface. If there be a free outlet the water-table would be the hydraulic gradient from the water-level in the tank to the outlet, and would vary with the porosity of the sandstone. If the sandstone were replaced by a block composed of layers of sand and clay the water-table would be an irregular surface; the water would rise to different heights according to the permeability of the material; the greatest possible height would be that of the water-level in the tank. If part of the block were heated by a lamp, then the water near it might be raised above the hydrostatic surface by gas pressure."

Distribution of underground water.

When the water is absorbed by the ground (Ref. Meinzer U. S. Geol. Sur. W. S. P. No. 489, 1923) some of it is held in pores of the soil near the surface. Most of it, however, sinks downward into deeper layers of the *regolith* the mantle of unconsolidated material which in most regions covers the bed rock—this it saturates, while some of it percolates still further into the pores, joints, fissures or other openings of the bed rock, wherever it can penetrate.

There is no such thing as a vast sheet of water underground similar to the surface of a sea, or lake, neither, except in very special rocks, are there any reservoirs, or big underground tanks as we have on land. The streams of underground water which water diviners so vividly describe have no real existence outside their own imagination.

The upper limit of this saturated zone is known as ground water-table. The water of the saturated zone is known as *groundwater*. This water is under hydrostatic pressure, and serves as the source of supply for springs and wells. The groundwater may extend to different depths in different localities, but on an average the porosity of the

rocks decreases as the depth increases. Most of the water in crystalline rocks is found within 300 feet of the surface. The popular idea that, if you go deep enough you must find water is not borne out in practice ; in fact, the reverse is nearer the truth. A very good instance in point is the Hutti Mine where water was more or less plentiful, requiring fairly large pumping plants down as far as about 700 feet. From that depth downwards to 3,000 feet the rock was so dry that water even for boring drill-holes had to be carried underground.

Extending from the water-table to the surface is the zone of aeration. See Fig. 3.

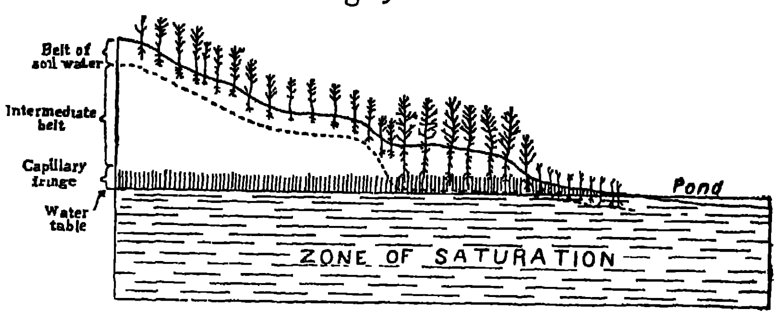

Fig. 3 :—Diagrammatic section showing the three belts of the zone of aeration and the saturated zone beneath. (After Meinzer, U. S. Geol. Sur. W. S. P. 489. 1923).

This Diagrammatic Section shows the three belts of the zone of aeration, in which the ground is usually only partly filled with water, and which, for the most part, is held by molecular attraction. This water is therefore sometimes referred to as suspended sub-surface water, which is particularly useful for the sustenance of vegetation.

The aeration zone may be further subdivided into (1) an upper belt of soil water, (2) an intermediate belt, (3) a lower belt of capillary fringe, lying immediately above the water-table and containing water drawn from the zone of saturation by capillary action. All these will at once be readily recognised by anybody used to sinking wells.

The upper limit of the groundwater, or water-table follows, though in a less marked way, the inequalities of the surface of the land. This is very clearly shewn in the sections along the Broad and Metre gauge lines of His Exalted Highness the Nizam's State Railway, drawn from information very kindly supplied by Mr. F. M. B. Rosenthal and his able staff, to whom I wish to express my gratitude. (Plates II and III). This water gradient rises highest in the hills and lowest in the depressions but is furthest removed from the surface on hill tops and rises nearest to the surface in the depressions or valleys. It shows the least slope in porous sand and the steepest slope in clays, so that, in the latter, it may follow the contour of the country very closely.

Water-table.

In solid rocks there is no continuous zone of groundwater such as is found in the subsoil, but the water, filling any connected joints and fissures, will tend to rise to the same average level. See Fig. 12, p. 76.

Above the main water-table small bodies of water are sometimes found which owe their presence to local beds, beds of clay, dykes, or other impervious material. At Mudgal, (Lingsugur Taluq, Raichur District), for instance, a mile south of the town there is a gneissic plateau strewn with boulders, 80 feet above the main level of the country where a good supply of water 4 feet below ground-level can be tapped throughout the year. It will be seen that at very little cost such water can be tapped and syphoned as a pure village drinking water-supply. The writer has lately located an excellent example of perched water-table in the hills above Surapur Town, Gulbarga District, in a valley south-west of the Tehsil Office where a large quantity of water is held up by a series of cross dykes. Thus, water which averages about 10 feet below the surface, lies 60 feet above the level of the Surapur bazaars and 500 feet above the average water-table of the Krishna-Bhima Doab, see Fig. 4 next page.

Perched water-tables.

I have examined many of the wells at the top of Deccan

Forts which local gossip claim to be perennial. There is no doubt that, in each instance, the fact that water does remain in these wells all the year round is correct, the reason being that nobody draws from them. They are one and

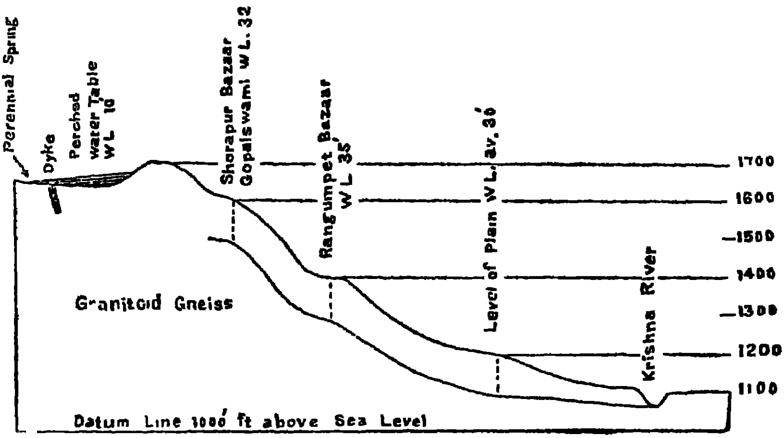

Fig. 4. Surapur town Perched Water-table showing water-level contour to the Krishna River.

all, including one big storage reservoir at Daulatabad Fort, merely underground cisterns which retain the collected rain water. These are not to be mistaken for perched water-tables.

Causes of fluctuation of water-table.

Fluctuations may be of natural or artificial character. Natural causes are rainfall, floods, sympathetic tides near the sea coast, temperature and pressure. Artificial causes are construction of big dams or reservoirs or their breaching, and the introduction of a large system of irrigation canals through a district.

The effect of rainfall on the water-level in wells is too obvious to discuss, but the question how soon the monsoon rains begin to affect the recuperation of wells is of great importance. No hard and fast rule can be laid down as so many factors come into play, *e.g.* surface soil, rate of rainfall etc. In the Raichur District it has been found that the underground water-table is not seriously affected

until late in September, but the rainfall during the term of operations since Thir 1337 Fasli (May 1928) has been most inconsistent. The range of water-table fluctuation between the end of the monsoons and the end of the dry weather in three wells in Lingsugur kept under observation was 8 feet with a total rainfall of 36·99″ for the period *viz*:—August 1931—August 32. Further enquiries into this question are under progress.*

Lacey in his " Hydrology And Ground Water, " page 101 mentions that observations at Ootacamund showed the range of groundwater level, for percolation wells, from the end of monsoon period to the end of the dry weather was 8 feet and the supply to the wells lagged two months after the rains.

Dealing with this question Lacey further writes on page 57, para 36.

" In comparing and analysing the surface yields of hydrographical basins due to the rain falling on them the period generally taken for comparison is that period of time in which the seasons complete their cycle, that is, a year; but it is obvious that the calendar year is not suited for such comparison, and the period of time for our purposes should be what may be termed the ' Water Year. ' The ' Water Year ' should begin when the groundwater plane of saturation is at its lowest level, or at its highest level, but as it is not always possible to ascertain the mean calendar month in which these conditions obtain, the water year is generally assumed to begin when surface or stream-flow is at its minimum or ceases altogether, and ends at a similar date the next year. If rainfall and surface yield are tabulated, starting from the calendar month, or the next succeeding month in which stream-flow is nil, or at its minimum, it will be found that the connection between rainfall and surface yield are more regular than when results are tabulated by the calendar year. In the British Isles and in the United States of America the water year will begin about September. In India the water year will begin at the end of the dry weather period, generally about the 1st June. In further analysing the surface yield of a basin, the total yield of a water year may not always be a reliable guide as to the supply available, as during certain periods of the year there may be little or no yield, although the total yield of the year may have been sufficient for requirements, and a further division of the water year into seasonable periods seems necessary.

* Information on this subject from other district would be most gratefully accepted and acknowledged.

"It is possible to ascertain from observations of rainfalls for a considerable number of years at a locality the wet and dry seasons of a year, and to divide the water year into periods when the relations of surface yield to rainfall are markedly different. American investigators divide the water year into three seasons, viz. (1) The storage period during which evaporation and transpiration are small, the surface yield large, and during which period the groundwater plane of saturation reaches its highest level ; (2) the growing period, when evaporation and transpiration are large, the surface yield is small and decreases to its minimum, or ceases altogether, and the groundwater plane of saturation sinks to its lowest level ; (3) the replenishing period, when, with normal rainfall, the groundwater plane tends to recover its level, streams begin to increase in flow and normal conditions are re-established."

The diminution of the rainfall has naturally a great effect on the level of the water-table. The Note published in the Annual Report of the Well Sinking Department for 1340 Fasli, (1930-31), illustrated with rainfall graph, map and sections, shows many instances in the western half of the Raichur District where the water-table has shrunk 10 feet and over, during the last 10 years.

It would be of great value if the Revenue, or Agricultural Departments could institute like surveys over the remainder of the State.

The British Association have laid down the following list of questions to be answered in the case of enquiries on wells :—

(1) The exact position of the well.
(2) When was it sunk ?
(3) What is the total depth of the well ?
(4) What is the depth of water below ground surface (*i*) end of winter (*ii*) end of summer.
(5) At what time of the year is the water-level highest, and at what time is it at its lowest level ? Is this level stationary, or are there signs that the level is rising or falling ?
(6) What is the character of the water ?
(7) Give the strata as far as possible through which the well has been sunk.
(8) Does surface water percolate into the well ?

(9) How long does it take before wet weather causes the water in the well to rise?

(10) Any further remarks.

If officers of the Revenue and Agricultural Departments would endeavour to obtain these answers from as many sources as possible, the Geological Survey would gladly tabulate and publish them for general information.

Artificial causes.

Many of my readers will remember the effect that the drying up of the Hussain Sagar Tank had on the lowering of the water-level in the wells in Secunderabad and Hughes Town. An opposite effect has, no doubt, come about, now that the tank is again full. This same result will happen in the vicinity of all big reservoirs of water which have the effect of raising the local water-table. The same result must naturally follow in the vicinity of irrigation canals.

Lower Limit of underground water.

That depth reduces the chances of finding water has already been referred to in the Section on distribution of Underground Water. Mining has proved that in crystalline rocks 250 to 300 feet is about the maximum at which water is found. Sedimentary rocks are of course different and water has been struck under artesian conditions up to 3,000 feet in depth. Deep mining has sometimes opened up hot springs of magmatic water, but such fortuitous occurrences do not come within the purview of this paper.

Movement of groundwater.

Groundwater tends to move in the direction of the steepest slope; so, roughly, the flow will be parallel to the surface drainage. Unseen obstructions beneath the surface may affect this, as will be seen later. In the ordinary case groundwater flows towards the valleys where it seeps into the channel of the stream. In some instances the groundwater is separated from the subsurface water by a bed of clay. This occurs in the stream which crosses the Lingsugur-Mudgal road at mile 6, furlong 2. The Well Sinking Department have taken advantage of this occurrence to divert the sweet rain-water

collected in the sand of the nullah into an underground cistern, as at that point the groundwater is saline. ($1 \cdot 5°$ B),* Plate XI.

Springs.

A spring may be defined as a natural outflow of water from the ground at some definite point, and from a rather definite opening. A seepage differs from a spring in that it has no definite opening.

Bryan, Journal Geol. XXVII, 1919, has classified springs as follows :—

1. Springs of deep seated origin. Supplied by juvenile or connate water admixed with deeper meteoric water. Show no seasonal fluctuation nor hydrostatic head. They include waters usually hot and more or less strongly mineralised.

   (*a*) Volcanic springs associated with volcanoes and commonly hot.

   (*b*) Fissure springs due to fracture extending into deeper parts of the earth's crust.

2. Waters, mainly meteoric, moving as groundwater under hydrostatic head, may fluctuate and flow with rainfall.

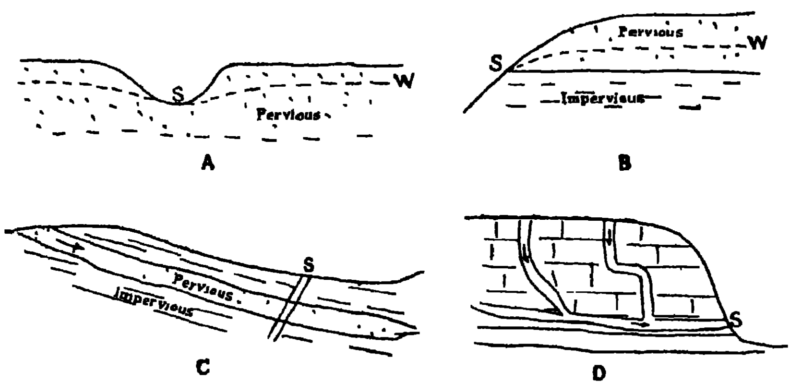

Fig 5.—Sections illustrating : A, depression spring ; B, contact spring ; C, artesian spring ; and D, tubular spring ; S=spring ; W=water table.

* B=Density (percentage of Salt in solution) as given by the Beaumé Hydrometer.

The following sub-types are recognised :—Fig. 5.

A. Depression springs due to the land surface cutting the water-table in porous rocks. Topographic location variable. Outflow usually a seepage.

B. Contact springs emerging from a porous rock overlying an impervious one. Flow of water due to gravity and discharge of water along upper edge of the impervious rock often in the nature of seepage. The watertight rock may be a cemented layer in sand, a bed of clay, or hard sandstone etc.

C. Artesian springs, caused by presence of pervious beds, between impervious materials. It is essential that the porous bed outcrops so as to catch the rainwater, and further more that it be inclined. Sedimentary rocks, alternating lava flows, tuffs, gravel, or clays may supply the requisite conditions. In some cases the porous bed may be crossed by a fault or a joint fracture along which the water rises towards the surface.

D. Springs in impervious rock, the water moving through openings of secondary origin. Two sub-types are : —

1. Tubular springs, in which the water flows more or less through tubular openings, such as solution channels in limestone.
2. Fracture springs, whose origin is due to water, collecting in and flowing from fractures, such as joints, planes of bedding, cleavage, or schistosity, or even fault fracture.

Artesian water.

This term *Artesian water* originally applied to water under sufficient static head that, if tapped by a bore, overflowed like the wells in the Province of Artois in France. For such a phenomenon to occur entails a definite arrangement of underground geological conditions consisting of a porous layer of rock

lying between two relatively impermeable layers, the porous layer being able to receive water-supply directly or indirectly from the rainfall. Figure 6 below, explains the necessary conditions in sedimentary rocks.

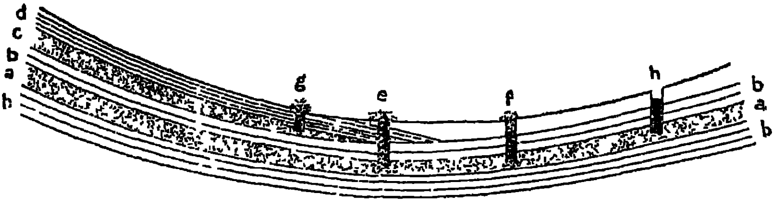

Fig. 6.—aa, porous layer, bb relatively impermeable layer, c, porous bed which thins out, overlaid by d, a layer of clay or shale, e, f, g, flowing wells, h, well with only semi-artesian effects.

The whole theory has been fully explained by Meinzer in a diagram which he gives in Water-supply Paper No. 494 of the U. S. Geol. Survey which is given below: Fig. 7.

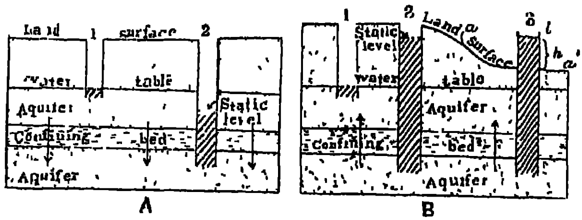

Fig. 7.—Sections showing hydrostatic pressure in aquifers and wells. In A the lower aquifer has subnormal head; its piezometric surface is below the upper surface of the zone of saturation, the resultant hydrostatic pressure on the confining bed is downward, and the bed may be called a negative confining bed. Both wells are non-artesian. The water in the upper aquifer is semi-perched—it belongs to the same zone of saturation as the lower aquifer. In B the lower aquifer has artesian head, its piezometric surface is above the upper surface of the zone of saturation and in some places above the land surface, the resultant hydrostatic pressure on the confining bed is upward, and the bed may be called a positive confining bed. No. 1 is a non-artesian well, No. 2 a subartesian well, and No 3 a flowing well. The static level of the water in the lower aquifer at the intake

of well No 3 is at *l*, and its pressure head with reference to the land surface is the vertical distance *h*. *aa'* is an area of artesian flow. (After Meinzer U. S. Geol. Surv., W. S. P. 494.)

On page 76 Fig. 12, will be found a diagram and description showing conditions under which artesian and semi-artesian effects can be found in crystalline rocks, and on page 77 Fig. 13, is a diagram of a well at Ghatkasar, mile, 12 on the Nizam's State Railway. The writer, when boring for coal, met artesian effects in the Asifabad District and also at Jangaon, Karimnagar District, in a bore-hole 1,300 ft. deep, but, in both instances the flow was but little, and in the latter case ceased when the casing pipes were withdrawn.

Owing to the greater portion of the State being composed of crystalline rocks and igneous lava flows, the chance of tapping permanent spouting water by boring is practically nil.

Under ideal conditions artesian water may be tapped miles away from the collecting ground where the porous rock receives its supply. In South Dakota, U. S. A., in the Great Plain, artesian water is tapped at the depth of 3,000 ft., 300 miles away from where the outcrop of porous shales receives its supply. The late Professor Gregory, who reported on the failing of the artesian supplies of certain bores in Queensland, has suggested that it was not static head that caused the artesian effect but that this was derived from rock pressure. Similar conditions have been discovered by American Geologists while studying the Wisconsin artesian systems.

Calculated total available quantity of underground water in a given area.

Very often the question of the possible total supply per annum, that any given area may be expected to yield from wells, becomes of very great importance. The solution to the question depends on all the various factors we have been dealing with above *viz.* :—rainfall, evaporation, run-off, porosity of soils and

underlying rocks, and the geographical character of the area under consideration.

The following formula may be used to calculate the total annual intake in areas of simple geological and topographical structure :—

> (*Absorption factor*)* × (rainfall in inches) × (catchment area in square miles) × 2,323,200 = the total cubic feet of water absorbed in one square mile of the area under consideration. The figure 2,323,200 represents the cubic feet of water received on the surface of one square mile with a fall of one inch of rain. This calculation however does not help us to come to any definite idea as to the available water in that area, but can be used as a guide to warn engineers against overpumping of wells within the area.

As regards average rainfall, besides deducting for run-off and evaporation, in reckoning the amount of available rainfall, it is customary to take the mean average of the locality and to deduct 1/5th or 1/6th as an allowance for three consecutive dry years.

Lacey in his "Hydrology And Ground Water" pages 102-03 writes :—

"If the area is not periodically fed by floods or surface waters, but the supply to the ground water is entirely dependent on rainfall alone, the supply or percolation to the ground water must be estimated on the principles laid down in Chapter IV. That is, the percolation will be the rainfall less losses due to transpiration and soil evaporation, the latter depending on the nature of the soil and the depth of the ground water plane below the surface. If the climate is arid and the variation in annual rainfall great, it is desirable to assume as the 'supply available' the ground water yield of the year of minimum rainfall, or the mean ground water yield of the three successive driest years. As a particular example, if the area under consideration is situated in the tract of insecure rainfall in the Ceded districts of the Madras Presidency

* This factor must be calculated for each area and is dependent on the conditions explained in this pamphlet, page 15 et seq.

"This paradox arises presumably from the fact that within the semi-arid region the rocks are widely exposed at the surface or possess a veneer of a relatively porous nature, display cracks that are open and unfilled with clayey matter, are but slightly decomposed and contain in their pores hardly any colloidal substances. The occasional rains are therefore able to penetrate them easily. In the area of high rainfall the rocks on the contrary are often concealed beneath deep loamy or clayey soils, are usually decomposed in depth and have their crevices and pores filled with amorphous or colloidal matter derived from extreme weathering of the constituent minerals. Infiltration will thus be hindered, as is also suggested by the high coefficient of run-off. Confirmation of this explanation is to be found in the observation brought out from the analysis of the records for the intrusive diabases of the Central Transvaal, that, where these rocks have become thoroughly decomposed to abnormal depths, the bore-hole yields instead of being large are well below the average. Many similar cases involving other formations could also be quoted in support of this view, which, while to my mind of fundamental importance, does not appear to have been recognized hitherto, for it seems to have been tacitly assumed that larger supplies should generally characterize regions of higher rainfall."

"The town of Raichur, like Adoni, given in table above, is situated in a tract of insecure rainfall. The mean average rainfall for the past 34 years is 21·92 inches and the lowest three consecutive years were between 1316-18 Fasli, (1907-09 A.D.) which was 16·23 inches. The highest and the lowest rainfalls occurred respectively in 1325 Fasli (1916 A.D.) 46·16 ins. and 10·29 ins. in 1316 Fasli (1907 A.D.). To the east of Raichur lies an area, as yet unsurveyed composed of highly acidic gneiss, apparently decomposed to a considerable depth, with very little soil covering, (see Fig. 11 page 72). Such a material has both high porosity and specific yield. The writer has drawn the attention of Government to this locality. His belief is, that wells sunk in this area and supplemented by others in the neighbourhood, might, if fitted with electric pumps, give sufficient drinking-water for Raichur town even in the worst years. The whole area should be most carefully geologically surveyed and the depth of weathering proved by bore-holes and trial pits. This investigation would only cost a few thousand rupees and might result in saving the State some laçs.

Water Finding

The necessary training to become a successful water finder is so various that it is very difficult to analyse.

First and foremost, undoubtedly, comes the gift of observation and deduction. The gift of observation, like the sense of direction, probably can be acquired, to a certain extent, but, primarily it is a gift of nature. It is surprising how many people go through the world with their eyes shut. The powers of observation do not apparently go hand in hand with advanced education, sometimes it would appear that the reverse is the case. It is only necessary to have watched an Australian black tracking a lost child (of 10 years old) over a bare granite outcrop to realize to what perfection observation can attain. The Indian on the whole, is not observant. Even the Ghond, or Koya, cannot rise to the tracking powers of his distant cousin the Australian. Many European and Indian geologists, highly trained in book knowledge, seem to have entirely lost, or failed to ever develop this most essential gift, or instinct, so highly developed in the aborigine.

Scientific imagination and the habit of considering the distribution of rocks in three dimensions are essential to a successful water finder. Scientific imagination must be utilized and kept in check by careful unbiassed deduction, remembering the caustic dictum of Huxley— " a working hypothesis is a capital horse to ride, provided he does not take the bit between his teeth and bolt with us. " In other words, prefer theories based on facts rather than facts forced to fit theories.

In virgin country, untouched by human activities, Nature's indicators of sub-soil water are more easily traced than in inhabited areas. Notwithstanding, these natural guides must not be overlooked. Richer luxuriance of foliage during the hot season and longer retention of leaves are sure indications. In uncultivated lands it is frequently possible to trace the line of some water-bearing fissure by the increased vegetation.

Growing crops of jawari often give excellent indications by spots of excessive luxuriant growth which must not be overlooked. Natural history also plays its part in helping the searcher. Swarms of gnats and white-ant heaps tell their tale.

Ground mists are an important line of observation. In the Wimemra plains of Victoria in Australia the rippling effect often observed by surveyors, caused by the variable refraction of light due to evaporation, are the subject of scientific observation, resulting in the discovery of sub-surface flows in channels traversing the primary rocks.* In more arid regions surface efflorescence is a feature to be carefully noted.

The general topography of the area is of course a vital study, combined with the geological conditions, but, as stated elsewhere, the configuration of the underlying rocks may bear no relation to the surface contours of the overlying soils (Figs. 11 and 12 pages. 72 & 76). Carefully noting the depth to water from surface in all neighbouring wells is an obvious necessity.

In this section it is unnecessary to deal with the geological side of the question, for that is treated elsewhere. The following are the chief geological features which especially affect underground water-supply.

Faults and Dykes, see pages 50, 76, 77, Figs. 10, 12, 13.
Hollows and pockets in weathered igneous and metamorphic rocks, page 72, Fig. 11.
Old river courses and alluvial beds. } p. 105 et seq
Alluvial areas and sandy river beds. }

Besides observation and deduction, a natural gift of common sense is also necessary in locating water. To mention that in general, wells should be sunk in low ground instead of high ground, because the natural drainage is in the direction of the low ground, would seem too obvious to mention, but yet the writer frequently sees the reverse being done, with no ostensible object. However, as stated above, this rule does not always hold good and sur-

* A. S. Kenyon, Proc. Aust. Inst. Min. and Met. Aug. 1928.

face configuration may have little influence on the sub-surface water supply.

The work of the water prospector entails the keenest study of nature in all her aspects. To most, the ever changing, never failing, loveliness of nature, is the chief delight and her all sufficient beauty satisfies them. To the water-seeker, however, she must tell her story, a story re-written like a palimpsest, a story which he can but dimly read, but, must ever strive to decipher more clearly. But even that is definite and tangible beside the pervading mystery of nature as an outward and visible, shadowing forth an inward and invisible. For those to whom that vision comes their work takes on a spiritual exaltation, they have seen.

> *"Gleams like a flashing of a shield; the Earth's*
> *And common face of Nature speak to them*
> *Rememberable things."*

Water divining.

Driberg in his "Savage as he really is," clearly shows that the savage never meddles with magic, except in relation to those subjects which he does not understand the why and the wherefore. A moment's thought will show that we who claim to be civilized have not risen much above this stage. Buckle* rightly says that, "if we compare the different classes of society, we shall find that they are superstitious in proportion as the phenomenon with which they are brought in contact have or have not been explained by natural laws." Meteorology, as a science, being still in its infancy, and the laws which govern winds, rains and storms, being in consequence still uncertain factors, it is only natural that the sailor and especially the deep-sea fisherman, who has to deal with other unknown laws controlling the migration of fishes, are undoubtedly the most superstitious of all the various classes of the British Nation. All grades of society have been known to show objection when asked, at Bridge, to vacate, what they considered, a lucky chair. With the improved knowledge of mathematics, the modern engineer no longer deems it

* Civilization in England. Vol. 1.

necessary to build a virgin into the first course of his masonry to ensure the stability of his dam. Yet, as the science of water-finding in all different classes of rocks has not yet been reduced to a certainty, the railway engineer calls upon the magic services of a diviner and the Agricultural Department pin their faith on a box of tricks. Following the same underlying principle, the writer learns, that the Telugu villager, to ensure rain, smashes the nearest Government of India Trig. point. As each of these states that his method sometimes gives most satisfactory results, they will probably continue to use them.

If all the money that has been spent and wasted on the employment of individuals who claim these magical powers, on the purchase of patent water-finders, on the unmethodical, unrecorded, badly located bore-holes and wells that have been drilled and excavated as the result of these magical prophecies, had all been allotted and scientifically spent by trained geologists, or geologist working hand in glove with physicists, probably by now the laws governing the existence of water in all different classes of rocks and strata in India, would have practically been reduced more or less to a rule of thumb. In a case on record £20,000 was entirely wasted by following such advice. The whole question has been reviewed by the late Prof. J. W. Gregory and republished in the Annual Report of the Smithsonian Institute for 1928.* Nobody, I imagine, after studying that report would place any further reliance on this variable gift.

du Toit, a leading South African Geologist of international repute, with whom the divining rod moves with a fair degree of consistency, writes† that he "has been driven to the conclusion that, as a strictly practical proposition, water divining generally has been, and is, a failure in South Africa. Isolated instances there are of unquest-

* Water Divining by J. W. Gregory (Paper at the session of the British Water Work Association, Public Works, Roads and Transport Congress 1927).

† Remarks on Water Divining. South African Irrigation Dept., Mag., Vol. II, pp. 35-41.

ioned successes by its means, but against these must be set a much higher proportion of failures." The argument that, in certain instances wonderful successes have been obtained by these means is analogous to the famous runs of luck at Monte Carlo which are for ever remembered and sometimes recorded in song, while the daily failures and even occasional suicides are quickly forgotten. Should any further literature be required the writer commends Mr. Frank Dixey's book, " A Practical Handbook of Water-Supply," not only in relation to this question, but as a thoroughly all-round useful, practical book and one that every engineer and agriculturist should have in his library.

Water Finding Machines.—To quote Dixey, " There is no doubt that the needle does oscillate or swing to one side under suitable conditions.. ...but they are of irregular character and may vary from time to time at one station....... The makers claim that the instruments can detect earth currents that pass between the earth and the atmosphere and are concentrated along bodies of underground water. No such currents are known, and the instruments as specified could not operate on the basis described by the makers."

As far as our Department is concerned the machine gave no oscillation at all, when tested round a well which has springs giving over 2,000 gallons per hour, but gave the greatest oscillations to the north east of a well which was dry and which sinking and tunnelling failed to improve. du Toit gives instances where bores gave 75,000 gallons and 14,000 gallons per day on lands where the machine gave no response.

It must be remembered that the water-table is widespread and in the kind of country where diviners and water finding machines are most successful, water occurs everywhere.

So much for water divining by human or machine aid.

Geophysical methods.

Even in the present early stages in the development of geophysical methods, valuable indications could be obtained of the nature of the underlying concealed geological strata of an area, which would render valuable indirect assistance in

the location of underground water-supply. Besides the Eötvös Torsion Balance, the single probe electrical method has been developed and has been usefully employed in determining depths at which solid rock for foundations will be met. Other electrical methods are under investigation and may develop into most useful factors for determining underground water-supply, if the expense is not too great.

However, the use of any of these methods, besides needing a highly trained man to conduct the experiment, must need the geologist to elucidate the results. So, for a long time to come, the question of water finding will properly remain the duty of the geologist.

The location and development of the water resources of any country is therefore, undoubtedly the duty of the Geological Survey Department, as it is a highly specialized task, requiring both training and experience. This can best be carried out by a geologist who has made a special study of the principles involved. This fact has now been fully realized in all Colonies of the British Dominions and in the United States of America.

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GREGORY AND ELLIS	Do	do	do	232.

PART III

Geological Structures and Weathering

By the term *tectonic* is meant in geology the broad structural conditions and relations exhibited by the stratified and other rock masses of which the earth's crust is built.

The tectonic features of the earth's crust

A large part of the outer rind of the earth, composing the continental areas, consists of stratified rocks. These rocks consist of material derived from the waste of older lands. They are formed largely in shallow seas and estuaries where they are deposited in practically horizontal beds. If the earth's crust were stable, the result of the process would be the total disappearance of the land and the complete conquest of the sea. The sea is easily able to swallow the material of the continents, and would soon do so, were it not that earth movements are continually affecting the relative levels of various parts of the land surface and the ocean floor.

The movement of the crust is due to shrinkage of the earth's nucleus, consequent upon continual loss of heat. Shrinkage of the nucleus develops stresses in the crust; and the crust adapts itself by a process of radial contraction or collapse and wrinkling, which results in a relative change of level at different parts of the surface In this way portions of the earth's surface which have long been buried under the sea and on which large masses of stratified rock have accumulated, become uplifted into land areas; and so we find land areas are largely built of stratified rock *

In the process of emergence, whereby a portion of the sea floor becomes dry land, a large region may be affected in such a way that the stratified rocks retain, over wide areas,

Horizontal disposition of strata.

* This opens too big a question to introduce into an elementary pamphlet such as this is intended to be. Those readers who would like to study the latest ideas of Isostasy with relation to Radioactivity I would refer them to "*Surface History of the Earth*" Clarendon Press, by John Joly, Sc.D., F.R.S. The best review of the whole question is to be found in "*Igneous Rocks and their Origin*" by Daly.

the horizontal or approximately horizontal arrangement under which they were deposited.

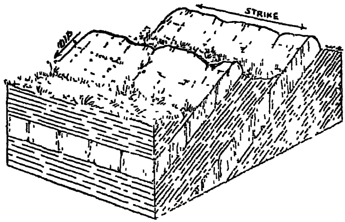


Fig. 8.—Illustrating Dip and Strike.

Dipping and folding of strata.

Very frequently, however, strata suffer some displacement from the horizontal, as a consequence of the disturbances which have affected them since they were laid down. In beds, which are not horizontal, the inclination of the plane of bedding is called the *dip* (Fig. 8). In such beds the direction of a horizontal line in the plane of bedding is called the *strike* of the beds and is represented as so many degrees East or West of North, *e.g.* Strike N 30°W, or N 30°E. The angle between the plane of bedding and the horizontal is called the *angle of dip*, and is shown on map by an arrow in the direction of the dip with the magnitude of the angle written along the shaft=10°/. Examples of the above may be seen at Shahabad to illustrate horizontal strata, and a good exhibition of dipping strata can be seen a few miles nearer Gulbarga, just before the same beds are overlaid by the Deccan Trap. Other instances of both occurrences are visible in the Dharwar, Vindhyan and Gondwana series of rocks (vide Geological Map).

Departures from the horizontal arrangement are well seen in many mountain regions and the worn-down stumps

of such regions, where the strata have been severely crumpled and folded under great pressure. The resulting arrangement of the strata is various. In some instances dome-shaped elevations, in other basin-shaped depressions have been formed. Most commonly, however, the folds have a linear arrangement and form ridges or mountain chains and valleys as the result of weathering and denudation.

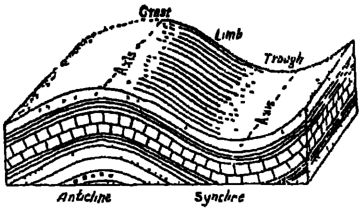


Fig. 9.—Symmetrical Anticline and Syncline.

The symmetrical linear type of folding is shewn above in Fig. 9. Such symmetrical, or approximately symmetrical folds are termed *anticlines*, when they are bent upwards as a crest of a wave, and *synclines*, when they are bent downwards as in the trough of a wave. It is in these latter, with suitable strata, that artesian water is struck.

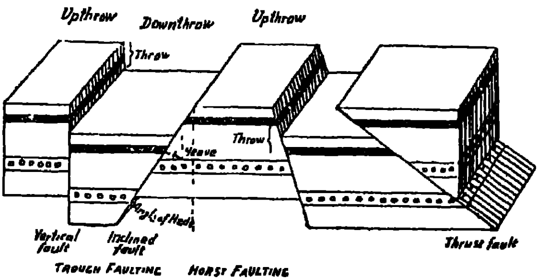


Fig. 10.—Diagram of Fault-Types.

Faults.

Normal faults are due to tension in the strata. Planes of fracture are developed with the result illustrated in Fig. 10.

When two normal fault planes dip towards each other they yield what is known as a *trough fault*. If successive

fault planes dip in the direction as in Fig. 10, above, they produce what is called *step faults*.

The subject of faults, and their cause etc., if fully dealt with, would occupy a far larger space than the whole of this pamphlet. The writer must therefore refer the reader to a text-book of geology for the further study of the subject. It is sufficient for the writer's purpose to show that these fractures in the earth's crust, in some places but small, and in other places having a throw of several thousand feet, have an enormous influence on the distribution of the water contents in the earth's crust.

Faults are frequently the cause of strong perennial springs, and, if cut in bore-holes, often supply artesian or sub-artesian water. It requires a very highly trained eye to discover their existence in igneous and metamorphic rocks, but in sedimentary rocks the juxtaposition of two entirely different types of strata often makes their identification easier.

Fracture zones.

Instead of being fractured along a simple fault plane, rocks are frequently broken by numerous fractures, through a zone of considerable thickness, in which there has been extensive shattering as a result of crustal movement.

Joints.

In consequence of irregularities in deposition, stratified rocks usually exhibit divisional planes parallel to the bedding, or split readily along these planes. In addition to these bedding planes, stratified as well as igneous and other rocks, that do not usually exhibit bedding, show other divisional planes, called joints, by which the rocks are split up into quadrangular blocks of variable size.

Joints arise from various causes. In some instances they are due to shrinkage. A notable instance of this is the columnar jointing in basalt, well depicted in the famous Giants' Causeway in Co Antrim. A local illustration from Purli, Parbhani District kindly supplied by Mr. R. Gregory, C. E., N. S. Ry., is shown in Photo Plate II, fig. 4. Another instance of jointing is the tabular jointing in granite

and granitoid gneiss, in consequence of which weathered outcrops of this rock assume a form resembling the bedded appearance of stratified rocks.

Weathering.*

Save where solid rocks are exposed on the surface, called in geology *outcrops*, for the most part the upper surfaces of rocks have been disintegrated or weathered and are sometimes termed the oxidized zone. This action is brought about by various mechanical and chemical processes. The former include the expansion and contraction of rocks due to daily and seasonal variations in temperature and moisture contents. The latter are due to the downward percolation of rainwater and soil water, which contains carbonic acid derived from the atmosphere and humic acids derived from the soil. These acids are capable of attacking the feldspars and hornblende constituents of the rocks, which they carry off in solution leaving *in situ* a porous gritty residue, generally coloured red, yellow, or brown, due to oxides and hydroxides of iron, which in India is termed *mooram*.

Under some conditions, as will be seen later (p. 72 Fig. 11), the weathering process extends to a great depth and wells can be sunk to depths over 60 feet without the use of any other tools than pick and bar. Sometimes the rock is so disintegrated that the soft and incoherent rotted material can be removed like loose sand. In spite of this rotting or weathering, the original structural features of the rock are preserved, and in granitoid gneiss, when a well is being sunk in the highly decomposed mooram, the original fissures and cleavages can be easily and clearly distinguished. See Photo Plate III.

The dykes that have been injected into rock formations of all ages and traverse the country, at times rising like saddle back ridges from the flat plain, often disintegrate by the same process into rounded boulders. These dykes are of two main classes, dolerite or diorite. Although generally found in an unweathered state at a shallow

* Following Meinzer, Dixey and Maufe.

depth below the surface, diorite dykes, especially, are sometimes weathered to great depths. In this connection Dixey mentions that in saline areas wells sunk in dykes have given sweet water ; but so far, in the writer's experience, he has not noticed such occurrences.

All the loose materials formed by these processes, together with the wearing of the exposed rocks by wind-borne sand, are easily washed or blown away, and form soil, their bigger members, by constant attrition, forming gravel and boulders. This material, when redeposited, forms alluvial beds sometimes of great thickness.

Such is the condition of things going on to-day, but it was not always so. Strange as it may appear, there is undoubted evidence that, at one period in the world's geological history, an *ice age* occurred over a long period, and glaciers heavily denuded the rocks of this State and other parts of India. The result of this *glacial period* was to form the Talchir boulder beds or the bottom beds of the Gondwana Series (see Table VI).

The great outburst of vulcanism in Cretaceous times which covered most of the State with the rocks now known as Deccan Trap, has been specially dealt with later (pages 89-92) and need not be referred to here.

Over the surface of both Deccan Trap and other rocks of the State is to be found a material which is known as *Laterite*. This rock is the result of sub-aerial alteration of the rocks *in situ*, mostly due to intermittent rainfall and insufficient underground drainage. Laterite has a wonderful power of resisting disintegration.

Now beneath all this superficial weathered material lies practically fresh or undecomposed rock. The writer does not wish to say that changes have not taken place, but no changes comparable with the changes that have occurred above in the oxidized zone.

In sinking a well in gneissic rock, before such undecomposed rock is reached we may have come to the water-table. But in country where, owing to long series of droughts the water-table may have sunk lower, it is not until we

excavate the practically un-decomposed rock that water is found. In rock of a more or less impervious nature all hopes of finding sufficient water-supply now depends on joints and fissures, as the rock itself has a high imbibition or power to retain its stored water. This point has been fully dealt with on page 20. These joints and fissures become rarer and further apart as depth increases and, at a depth of about 250 feet, the weight of the overlying mass of rock is so great that the joints are not sufficiently wide to allow a free flow, even under a head of 150 feet of water. A practical conclusion follows. In granitoid gneissic country deep boring for water has little chance of success. It means striking one of the open fissures which, mining experience proves, are not common.

TABLE VI.

Geological sequence of rocks in His Exalted Highness the Nizam's State.

(Rocks in Italics are potential sources of underground water).

Fossiliferous	Aryan Group	*Recent alluvium :—blown sand : talus at foot of hills :—mooram,* black cotton-soil, *Low-level Laterite* : (water found at junction with unaltered rock).		Recent.
		Older alluvials of Godavary, Tungabhadra, Krishna and Bhima rivers. High level laterite : (water found at junction with unaltered rock).		Pleistocene
		Upper, Middle, and Lower Deccan Trap and *inter-trappean* and *ash beds* (alternating layers of volcanic rocks total area in State limits 32,000 sq. m. Some highly decomposed layers supply large quantity of water)		Cretaceous
		Chikiala Beds *Kota Malari Beds*	Upper Gondwanas.	Jurassic.
		Kamthi Series *Panchet Series*	Middle Gondwanas.	Triassic.
		Barakar Series *Talchir boulder beds*	Lower Gondwanas.	Permian.
		(Mostly sandstones, and shales : all aquiferous, especially along lines of faults. Talchir water sometimes a little brackish).		

Representative rocks of Carboniferous, Devonian or Cambrian periods (Dravidian Group) are unknown in the State. The beds in the Salt Range, Punjab, yielding the Cambrian fossil, Neobolus, are the basis from which all other geological strata are compared with European Geology.

Unfossiliferous	Purana Group	Vindhyans	Upper Lower	*Limestones, Sandstones, Shales and Conglomerates.*	Pre-Cambrian.
		Cuddapahs.	Upper Lower	*Quartzite, Slates, Sandstones* and *Limestones.*	
	GREAT EPARCHEAN INTERVAL.				
	Vedic Group	1. Newer Granites and Gneisses, (Peninsular Complex). Water occurs in joints and fissures. 2. Dharwars. *Chloritic and Hornblendic Schists, Hæmatitic Quartzites*; and hard trappoid rocks, all veined with quartz reefs. *Schists*, water occurs in joints and fissures			Archæan.

Introduction to the Historical Geology of Peninsular India.

The Geological Table overleaf is but a bare catalogue of the rocks in their chronological order, occurring within the State. The writer feels that some short description is here called for to explain the main chain of events in the geological history of Peninsular India and to give some life and interest to this bare table of facts. In the following short summary he will endeavour to detail the succession of the main important geological events which have led to the present surface appearance of the State. The writer earnestly hopes that this short introduction may have the effect of inducing some of his readers to face the drudgery, necessary to the grasp of any science, so that they may master and gain a working knowledge of this very important subject. Once the initial effort is made and the elements fully grasped, those that take this advice will find it opens up such a fresh outlook on the world and scenery around them, that they will never regret the effort.

The Peninsula of India is one of the oldest rock masses now exposed on the earth's surface. There is no existing evidence to show that this area has ever been beneath the sea since Palæozoic times. The geological history of the Peninsula is quite distinct from that of the extra-Peninsular India.

The greater portion of Peninsular India, and at least one-half of Hyderabad State is composed of what is termed the *Peninsular Crystalline Complex*—a family of acidic rocks of the granite variety, all more or less similar in composition, but chemically and mineralogically divisible into many sub-types.

The reader may safely try to visualize our globe as once a cooling molten mass composed of 89 elements in certain proportions. As a matter of fact, for general purposes, it may be taken that of the *Lithosphere*,* which is that part

* Geologists divide our planet into the Atmosphere, perhaps 150 miles thick, the Hydrosphere, or the shell of water covering about three-fourths of the surface of the Earth and which if spread out would be about 8,000 ft. thick; the Lithosphere, or the continental crust and the central core which is termed the Endosphere.

of the outer crust of the earth, probably 100 miles in depth, the surface of which is available for human study, 98.5 per cent. is composed of the following eleven elements: *oxygen*, *silica*, *aluminium*, *iron*, *calcium*, *magnesium*, *sodium*, *potassium*, *carbon*, *sulphur* and *chlorine*. It is the combination of these eleven elements under the influence of intense heat and pressure which supplies the hundreds of diffeernt species of rock known to geologists.

As a simple classification which may help the reader to grasp the problem, these rocks of the crystalline complex may be divided primarily into three groups, thus :— Class A. rocks containing a small proportion of silica, but large proportions of magnesium, calcium and iron called *basic* rocks ; Class C. rocks containing a high percentage of silica, but small proportions only of magnesium, calcium and iron called *acidic* rocks. Between these we have Class B. of intermediate composition.

Name of type	Class	Facies	Texture	Component minerals
A. Gabbro	Basic	Plutonic	*Holocrystalline	Feldspar, Augite, Olivine Magnetite.
A. Basalt		Volcanic	Glassy to Holocrystalline.	Feldspar, Augite, Olivine, Magnetite, Glass.
B. Diorite .	Intermediate	Plutonic. .	Holocrystalline	Feldspar, Augite, Hornblende.
B. Andesite		Volcanic .	Glassy to Microcrystalline	Feldpar, Augite, Glass.
C. Granite .	Acidic	Plutonic. .	Holocrystalline	Quartz, Feldspar, Mica.
C. Rhyolite .		Volcanic .	Glassy to Semi-crystalline	Quartz, Feldspar, Glass.

* Holocrystalline in the above table means wholly crystalline, the crystals being discernible to the naked eye ; micro-crystalline explains itself and so does the term glassy.

Petrology further divides each of these classes according to their crystalline texture, the larger crystals indicating

slow cooling at a depth under, what is termed, *plutonic* conditions, and the finer indicating rapid cooling near the surface under volcanic conditions. The table above shows these three classifications combined together with the principal component minerals of each rock type.

These rocks, geologically, are termed igneous rocks and we believe that all of them, as well as many other minor types, are derived from the molten rock, *magma*, which underlies the continental crust of the earth and that their difference is due to physico-chemical causes, a subject too complicated to be dealt with incidentally in this place.

Directly this earth became cool enough for water to condense, disintegration of the then (probably very thin) crust of this earth commenced and sedimentary deposits must have been formed. None of these earliest sediments are now recognizable on account of the great alterations they have undergone owing to heat and pressure; but some of the schists and gneisses may represent these earliest sediments. We know that at this earliest period this globe was far from being quiescent and in Peninsular India and elsewhere huge vulcanic disturbances took place, when, as in later years, now represented by the Deccan Trap, vast sheets of lava were extruded and covered the crust. These earliest lava flows were subsequently invaded, engulfed and partially absorbed by the newer intruding igneous rocks, which we now call the Peninsular Crystalline Complex, and have been remelted and altered nearly beyond recognition. These primeval lavas are now represented by a series of schists and hornblendic rocks, which are called the *Dharwar Series*. These rocks are found included and folded amongst the newer igneous rocks of the crystalline complex as denuded stumps of what must once have been a far greater exposure.

Now, taking our Dharwars and Gneisses as the oldest rock known to us, it follows that, for every square mile of newer rocks subsequently formed, a corresponding waste or denudation of these older rocks must have occurred, and this is very important when we are considering the

lapse of time required for the formation of any thickness of stratified bed. For, we are forced to the conclusion that it must have been these and other fundamental crystalline rocks which were worn down by atmospheric agencies such as are at work around us to-day.

The beds which were formed from the waste of the primitive crust must have been deposited horizontally on the bottom of the primeval seas in thick masses covering the original rock. This new deposit must again have been hardened and consolidated by pressure and heat, and in some cases partly and even wholly re-crystallized by these agencies. Over and over again these sediments were upheaved and submerged and worn down by fresh erosion, to form fresh deposits, which again underwent a repetition of a similar process, thus forming the various strata which we are now going to consider.

A great hiatus occurs in the story told by the rocks between the engulfing and subsequent partial denudation of the Dharwars and the next chain of events. This period is known as the *Great Eparchean Interval.*

The next scene in the geological history of Peninsular India is a long period of subsidence of a large portion of the area beneath what has come to be termed the *Purana Sea.* To what other continents India was then joined, or what the continental earth masses then were, it is now impossible to say. This subsidence continued, apparently spasmodically over a very long period, but of such a great length that it was sufficient to allow 20,000 ft. of sediments to be deposited. An examination of these so-called *Pre-Cambrian* rocks, termed the "*Purana Group*" in Indian nomenclature, shows that subsidence and sedimentation was not always continuous; so a further time interval must be allowed. It has been suggested that the time interval required for the formation of the Pre-Cambrian rocks is probably greater than that required for the deposition and formation of all other rocks now forming the earth's crust, perhaps 62 per cent. of the total period which represents geological history. These sedimentary and unfossiliferous

rocks, later described under *Cuddapah and Vindhyan systems*, are composed in the main of limestones, slates and quartzites. One of the main interests attached to these rocks is the fact that one bed of conglomerates is diamondiferous and it was the diamonds disintegrated from that bed and re-deposited in the alluvial beds along the Krishna river that made Golconda famous. (See Journ. Hyd. Geo. Sur. Vol I, part 1)

Again we come to a period unrecorded in the history told by the rocks. From the absence of evidence of any great earth movements which have left these sedimentary rocks for the most part lying horizontal, it may be presumed that a period of quiescence existed. Slight alteration of these sedimentary rocks gives support to this idea, but other factors suggest that other formations long since denuded may once have overlaid them. Even a most cursory study of the geology of Peninsular India must at once impress any observer with the enormous amount of denudation the area has undergone throughout the whole period of geological history, and is still undergoing.

The scene next portrayed by the rocks, curious to relate, is an ice age. Geologists are satisfied that at this period of the world's history, India was part and parcel of a continent including Madagascar, parts of South Africa, Australia and parts of South America.

That area of the Pacific, south and south-east of India, now sprinkled with islands, of which Java and Sumatra are the biggest, was a separate large island. The northern and southern hemispheres were separated by a girdling sea known as *Tethys*. This southern continent has been given the name of *Gondwanaland*. The effects of this ice age are visible from Bengal to New South Wales and from South America to South Africa. The cause of this widespread glaciation is still a matter of controversy.

The effect in India was to form a series of glacial beds known as the *Talchirs*. One of the finest proofs of glaciation at this period in India is to be found within the State, at Sullavai in Warangal Subah, and in the Asifabad District.

Here huge boulders carried from afar can be seen and the exposed rocks are deeply scored with striations caused by the grinding boulders dragged by the glacier along their surface.

Subsequent to this ice age certain portions of Peninsular India and Bihar and Orissa underwent a period of subsidence and in the depressions, lakes and marshes were formed and a series of sandstones and shales were deposited, the lower zone of which is interbedded with coal measures. This whole system, including the Talchirs, is known as the *Gondwana Series* and is included in the *Aryan Group* of Indian nomenclature. The whole system is fossiliferous, the most distinctive fossil being that of the leaves of two flora called *glossopteris* and *gangamopteris*. These plant fossils, relatively rare in Europe, are found all over the old Gondwanaland, described above, and constitute a big piece of evidence in defining the old continental boundaries. The uppermost beds of this series are known as the *Kota* and *Maleri beds*, from villages of that name, on either side of the Pranhita River. These beds are of great interest, as they contain fossils of ganoid fish and reptiles which connect the geology of India with that of South America.

The next beds that are known tell a like story of vast areas of marshes and lakes in which roamed the dinosaur and other extinct reptiles, some of extravagant dimensions, 15 ft. high and with tails 75 ft. long. Dr. C. A. Matley, representing the Percy Sladen Trust, has this year excavated the bones of one of these prehistoric extinct monsters from such beds near Jubbulpore. There is more than a possibility that the remains of some of these monsters may be discovered in this State in the so-called *Lameta beds*, which frequently are found obtruding from beneath the series of lavas known as the *Deccan Traps*. Those officers in State Service whose duties lie in those areas, clearly shown on the geological map, should especially study this period of Indian geology and keep their eyes open. It is quite possible that a chance discovery, properly reported

by one of these officers, so that the bones can be extracted by an expert, may lead to his name being included in the select band of famous discoverers.

The story of the catastrophic period when the masses of Deccan Trap lava flowed over Peninsular India has been fully dealt with later in this pamphlet on page 89, and an attempt has been made there to help the reader to realize the then prevailing conditions. It is enough here to say that these rocks are of *Cretaceous date* and form part of the Aryan Group of Indian nomenclature, and are conterminous with the rise of the Himalayas. This period saw the break up of Gondwanaland, and next year " S. S. MABAHISS, " manned by a technical staff, is to be fitted out to take soundings between India and Madagascar and to attempt to demarcate that submerged continent.

This brings us now to what is termed the *Tertiary* and *Recent* periods, the main interest of which is connected with the evolution of mammals and man's appearance on the scene.

And how, the reader will ask, have geologists managed to arrive at such definite conclusions with regard to the thickness of the strata and its relative age? To answer this question fully requires far more space than can be allotted in this pamphlet, but the following bare statements will, perhaps, throw sufficient light on the subject to make the principles intelligible. First and foremost, it is obvious, that in any succession of sedimentary rocks the lowest, having been deposited first, must be the oldest. This is the *Law of Superposition* on which all our ideas of chronology are based. Dealing with this subject in the introduction to " The Geology of the Nizam's Dominions, " published in 1915, the writer used the analogy of a book, in comparison with horizontal bedded rocks. He pointed out if a book lies flat on the table, a bird's eye view gives no idea of the thickness, but, if the book is viewed on edge its thickness is at once apparent. So it is with bedded rocks, which fortunately for the geologist, owing to earth movements since their deposition are frequently found lying at

an angle, or as geologists say, dipping, while sometimes a river has cut vertical sections through the beds exposing their thickness. But even in such cases the whole thickness of the series may not be exposed in one locality. In one area we may find beds *a*, *b*, *c*, *d*, and further afield *c*, *d*, *e*, *f*; *e* and *f* being obviously a continuation of the series. In such a manner, often after long research, the whole series is pieced together, and the total thickness estimated.

But another difficulty arises, which the Law of Superposition will not always solve. Even the most casual observer, who has visited the sea coast, or for that matter a large lake, or tank, must have observed that rivers and nullahs carrying down the gravel and sediments, as soon as the sea or lake is reached, owing to the check to their current, deposit their heaviest particles first while their lightest sediments are carried far out beyond the shore line. The result is, that, when these sediments are consolidated and again upheaved, we may find one part of the original sea floor, which once was sand, altered into sandstones, once mud, now appearing as shales, while further afield we may find limestones chemically deposited; and yet all these deposits were contemporaneous. How does the geologist obtain any correlation in such a case? This question was solved in 1796, by William Smith, an English Engineer, who, in one of the most outstanding discoveries ever made, which places his fame on a level with that of Galileo, Newton or Darwin, discovered the principle regulating the occurrence of fossils. *Smith's Principle* (or the law of organic correlations) is that certain fossils are found in certain systems of rocks and only in those systems, never in underlying or overlying systems. This has since been tested innumerable times and invariably found true. Smith's Principle, combined with the Law of Superposition, has enabled geologists to unravel the sequence of geological history of this planet from the earliest geological times.

Smith's wonderful discovery, which has caused him to be

called the Father of Geology, also opened to us the book of the history of life of this planet. Let us for a moment forget the strata and their terrifying names, but confine our thoughts to the fossils included in those beds and the species of plant, or animal life they once represented. *Palæontology*, or the scientific study of fossils, which really only started less than 200 years ago is still in its infancy, for although more than 100,000 extinct species have been found and classified to date, there are still vast tracts of the earth's surface whose rocks have not yet been fully examined. An example may be cited from a recent issue of the "Pioneer," where the discovery in Australia of a marsupial lion, which existed about two million years old, was reported. As our examination of the fossils discovered in the beds proceeds, it is noticed, that the older the beds, the fewer the examples of living species are found, so that at last in the oldest beds only extinct species of life are represented. Some species such as the scorpion, first found in the Silurian beds, has remained practically unaltered even to-day, but the scorpion and two marine shell forms are outstanding exceptions. To quote from Huxley's lecture: "*On a piece of chalk*," the fossils prove that from the Cambrian period to the present "the population of the world has undergone slow and gradual but incessant changes. There has been no grand catastrophe—no destroyer has swept the forms of life of one period, and replaced them by a totally new creation; but one species has vanished and another has taken its place; creatures of one type of structure have diminished, those of another increased as time has passed on. And thus while the difference between the living creatures of the time before the chalk (Cretaceous period) and those of the present day appear startling, if placed side by side, we are led from one to the other by the most gradual progress, if we follow the course of nature through the whole series of those relics of her operations which she has left behind." Another point should be borne in mind that, although no undoubted fossils are found below the Cambrian system, yet the fossils found in those beds re-

present such highly developed forms of life that they in themselves are clear proof of a long antecedent period of life on this planet. In Pre-Cambrian, sometimes classified as *Archeozoic* (primitive life) and *Proterozoic* (early life) rocks, owing to heat and pressure (*metamorphism*) nearly all fossil remains have been obliterated, but certain specimens have been discovered which some geologists claim to be remains of primitive aquatic and marine life. The table below, after '*The Earth*' by Edward Greenly, (Forum Series, price 7d.) which the writer commends to all his readers, tells the tale of the evolution of life on this earth.

Rocks grouped by ERAS	Rocks grouped by EPOCHS	First known appearances
NEOZOIC (new life)	Holocene. (Recent)	
	Pleistocene	.. Man
	Pliocene	.. Man ?
	Miocene	.. Anthropoid Apes
	Oligocene	.
	Eocene	.. Placental Mammalia, First still-living species
MESOZOIC (middle life)	Cretaceous	.. Flowering Plants
	Jurassic	.. Birds
	Triassic	.. Non-Placental Mammalia
PALÆOZOIC (ancient life)	Permian	.. Reptiles
	Carboniferous	. Amphibia
	Devonian	..
	Silurian	.. First Vertebrates (Fishes) scorpions
	Ordovician	.. First Land Plants and Animals (Insects).
	Cambrain	.. Brachiopoda, Lamellibranchiata, Crustacea.
PRE-CAMBRIAN SYSTEMS.		Possible remains of aquatic life

To close this Introduction, a word must be said as to geological time. Here we enter the realm of uncertainty, but the period we have to contemplate must be immense to allow for the 25 miles, which is a fair estimate of the total thickness of sedimentary rocks composing the earth's crust, to have been deposited, not counting those beds which may have been deposited and entirely obliterated by subsequent disintegration and so for ever lost.

The suggestions, made thirty years ago by Kelvin and Tait, that 10 to 20 millions of years were necessary to account for this have broken down since the discovery of radio-activity. Calculations made from the rate of change in the composition of certain radio-active rocks suggest a period approaching, perhaps exceeding, 1,000 million years. However, this method of calculation is in its infancy and it is advisable to withhold any judgment. Reservation, however, is not withheld on account of the enormous length of the period, for calculations based on recent physics and stellar astronomy have suggested periods approaching 10,000 million years, but before such a figure the mind reels. Schuchert, a great authority, accepts the estimate of 500 million years which is based largely, but not wholly, on radio-active evidence. Knopf, another leading authority, states that the data based on radio-activity indicate the ratio of time required for the deposition of *Neozoic* (new life) to *Mesozoic* (Middle life) and *Palæozoic* (ancient life) is as 1 : 2 : 5. This ratio would require that one foot of sandstone would be deposited in 450 years, one foot of shale in 900 years, and one foot of limestone in 2,250 years.

This must conclude the summary of the tale written in the rocks of Southern India. Within its pages are to be found some chapters of the great book of life, though many of the pages and whole chapters are missing. We can read the story of this earth when it had only just passed beyond its molten state though these earliest chapters are faded and indistinct. But throughout the tale we read of endless metamorphoses between land and sea, deposition

and disintegration, without haste, without rest, and one awful story of a catastrophe which temporarily obliterated all life from a large area of the whole peninsula.

Turning this story into song, truly did Tennyson write :-

" The hills are shadows and they flow
From form to form, and nothing stands ;
They melt like mists, the solid lands,
Like clouds they shape themselves and go."

The following is a list of some of the wonderfully cheap books on Geology, now available, written by the best authors, all of which are strongly recommended :—

GREGORY, J. W.—The making of the Earth, Home University Series
Do The Geology of To-day. Seeley, Service & Co., London.

HOLMES ARTHER.—The Age of the Earth. Benn's Six Penny Library No. 102.

HAWKINGS, H. L.—The Restless Earth. Routledge, Introduction to Modern Knowledge, No. 10. 6 d.

GREENLY, EDWARD —The Earth. The Forum Series. 7 d.

WOODWARD, H. B.—Geology Popular Science Series. 1 s.

COLE GRENVILLE.—Rocks and their Origins, Cam. Man. of Sci. and Lit.

BONNEY, T. G.—The work of rain and rivers. Cam. Man. of Sci. and Lit.

BONNEY, T. G.—The Structure of the Earth. The peoples Books. T. Nelson, Edinburgh.

THE ARCHÆANS

For the purpose of this pamphlet there is no advantage in differentiating between the *Granitoid Gneisses* and the *Dharwars** both of which will be classified under the term of *Archæan Crystalline Complex*. The Archæans collectively comprise about half of the area of the Dominions. They will be dealt with here only with regard to their several characteristics on which their water-bearing qualities depend.

The *Crystalline Complex* viewed from this angle may be fairly divided into :—

1. Bosses of granitoid gneiss and massive hornblende rocks impervious to water and practically without joints and fissures. See Photo Plate I, Fig 1.
2. Gneisses, schists and quartzites of all varieties, impervious themselves, but highly fissile and jointed.
3. Fine and coarse-grained highly siliceous rocks with a laminated appearance, technically, described as compact quartzose grey gneiss veined with acidic stringers and illustrated in Photo Plate IV, Fig 1.
4. Intrusive dykes, and quartz veins. (Photo Plates IV, Fig 2. and III, Fig 2.

A complete geological and petrological description of these rocks will be found in Vol. I, Part i and Vol. II, Part i of this Journal.

The term, *Granitoid Gneiss*, is used rather than the ordinary term *Granite*, not in any pedantic spirit, but purely for the reason that it helps to describe the nature of the rock in question. Technically speaking there are very few instances of *true granite* within the State.

The term *Gneiss* is a very old word used by Saxon miners, and has had rather a loose geological usage. It

* The Dharwar series, as far as it has been mapped is shown on the accompanying map. However, other areas are known to exist in Nirmal, Nizamabad, Karimnagar and Nalgonda taluqs.

was originally applied more particularly to laminated rocks having the composition of granite, *viz*: quartz, feldspar and mica. They were originally supposed to be an altered sedimentary rock. For the purposes of this pamphlet, gneisses may be described as banded metamorphic rocks whether originally of igneous or sedimentary origin. The bands of these rocks are mineralogically unlike and consist of interlocking crystalline mineral particles which for the most part are large enough to be visible to the naked eye. The bands may vary in regularity and in thickness from a decimal of an inch up to many inches.

The term *Schist* like gneiss has also a loose geological usage and has been employed in a dual sense to cover structure and mineral composition. Following Van Hise in the definition of gneiss, schist in this pamphlet is defined to include those metamorphic rocks, whose individual folia are mineralogically alike, and whose principal minerals are so large as to be visible to the naked eye. The definition is uniform with that of gneiss and slate, into either of which schists may grade. For this reason no hard and fast line can be drawn between schists and gneisses, and, by becoming finer in grain and texture, the schists may grade into slates.

Metamorphism.

A word must be said here with reference to the meaning of the term *Metamorphism*. The term strictly means "a change in form" and was introduced by Lyell to express the changes of sedimentary beds to slated quartzites, crystalline limestone etc. Later, it was extended to cover the development of gneiss, schists and slates from igneous rocks by heat, pressure and recrystallization, and it is in that sense the term is used in this pamphlet.

Weathering of crystalline rocks.

For the general study of the rocks of the crystalline complex from the water-finding point of view, it seems to the writer that the most useful thing an engineer can do is to study the exposures (*outcrops*), of these rocks or examine their sections in quarries. He can take it for

granted that the structural conditions below ground are identical to those conditions now exposed on the surface.

Plate VI gives a Hypothetical Section from S-W to N-E across Hyderabad State, indicating the chief rock types.

Now, in all the rocks of the crystalline complex, save in their highly weathered and disintegrated remnants, the rocks themselves are, as we have shown above, so retentive of their stored water that they are useless as a water-supply. So, from a water-finding point of view the joints, cleavages and fissures in these rocks must be the main object of our study.

The granitoid gneisses throughout the State have generally three main cleavages. The biggest vertical cleavage seems to run roughly in a northerly and southerly direction. There is a second cleavage more or less at right angles to this, and there is a horizontal cleavage plane at very irregular intervals. The result of these planes is to split up the rock, on weathering, into rhomboidal boulders. These cleavages occur at intervals, and their effect is illustrated in Photo Plate I, Figs 2 & 3.

It is along these joints that the rain water, or soil water attacks a mass of granitoid gneiss, causing a rotting of the joint surfaces which is naturally most effective at the corners where two surfaces meet. This process is going on continually underground. By this means a rectangular block of granitoid gneiss tends to become spherical in shape. This weathering action produces the piles of heaped up boulders so common in these Dominions, which look at times like a pile of monstrous bricks untidily left lying about in a playground by some wayward baby giant. See Photo Plate I, Fig. 3.

Some gneissic rocks are veined with highly crushed quartz veins which act as water channels. These network of cracked and broken quartz veins traversing the gneiss often occur over fairly large areas. Wells sunk in such localities often give big supplies of water. See Photo Plate III, Fig. 2.

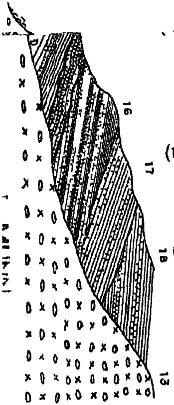
PLATE. VI

System of Sedimentary rocks

interbedded with clay Shales and coal beds at lower half of Series frequently highly faulted. This Series in places overlap the Talchirs completely concealing them.

(17) Kamptee sandstones, clays, and quartzites, these beds sometimes overlap the Barakar series

(18) Kota Maleri beds.



As stated above, the underground conditions are fully illustrated on the surface, and there are as many bosses, like Moula Ali or Bhongir, see Photo Plate I, Fig. 1. lying as yet unexposed beneath the surface. But a careful examination of these bosses will show that, although weathering has now removed all the onion-like skin which once surrounded them, at one period in the world's history their surface was not unlike the weathered tors you see at Lingampalli. This is another proof that mere depth is not the decisive factor in finding water. As you go deeper the fractures and joints become less and less, and further apart, and mining has proved, that, save in exceptional cases after 250 ft., springs of water are exceedingly rare.

Under certain conditions granitoid gneiss is weathered into what Engineers of the Public Works Department classify as rocky mooram and which extends to very great depths. The Well Sinking Department have sunk many wells in mooram, down to even 50 ft., in which no solid rock was encountered, the average water-table being 25 ft. from the surface. Weathering of rocks has already been dealt with more fully on page 52, but it is necessary to mention here that *hydration*, or the assumption (acquisition) of water in crystalline rocks, is one of the greatest causes of disintegration. The hydration which results in formation of hydro minerals involves expansion in volume and liberation of heat. According to Van Hise the increase in volume, may increase as high as 160 per cent., but commonly the increase is less than 50 per cent. Although hydration involves increase of volume, the rocks do not find room to expand. Engineers, engaged in well sinking, or tunnelling have noticed, how sometimes apparently fresh rock, when brought to the surface, exfoliates and crumbles rapidly. This is because the rock, whose minerals are partly, or wholly hydrated, is under great strain whilst underground and directly the pressure is released it disintegrates rapidly. This action should be carefully watched, else it may be found that apparently solid rock, intended as the ledge, or as the

permanent future walls of a well, may in a few weeks exfoliate and crumble to pieces.

Reference has already been made on page 22 to basins of soil holding large volumes of water. The individual members of the gneissic complex do not decompose uniformly with equal facility. Owing to their composition a large range of rocks, which may be technically defined as *acidic binary gneisses*, frequently weather to a great depth forming deep hollows for holding big potential sources of underground supply.

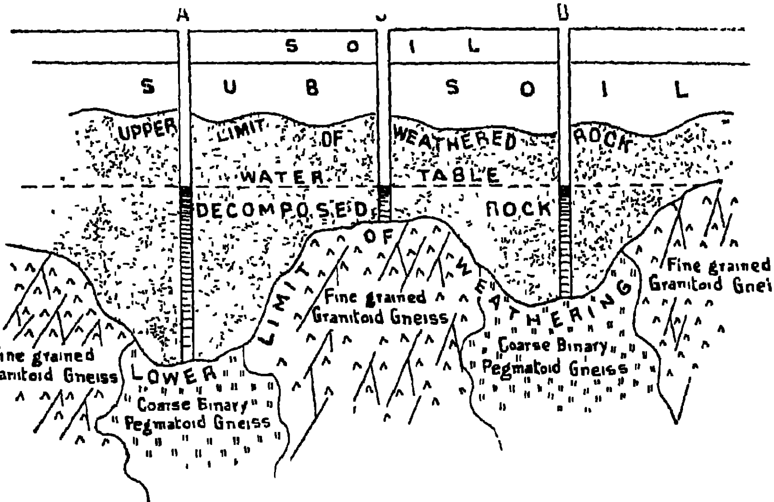


Fig 11 above, illustrates this possibility and it will be obvious that wells sunk at A and B will give a far greater supply than that sunk at C. This explains the reason why wells, often close together, give such variable supplies. (Coarse binary pegmatoid gneiss is a variety of acid binary gneiss.)

The occurrences of these bands of highly decomposed rock are far from rare in the Raichur District. In this treeless country, the writer has so far found no key by which to detect their presence below the mantling soil. Examination of irrigation wells throughout the Crystalline Complex area of the State will show that generally the most prolific wells have been sunk in this type of material. Owing to their origin they are closely intermingled with the other

members of the Crystalline Complex. They sometimes extend over wide areas. It would appear from the evidence to hand that most of the area between Kurkundi and Narbundi along the Hutti-Sirwar road, a distance of 4 miles (see Geological Map) is mostly occupied by these decomposed rocks. Their range north and south is not known. Another area has been noted to the east of Raichur with Vedvatti village about the centre. The total area is unknown, but examination suggests that between this area and the Krishna river lies a band of impermeable grey gneiss which acts as an underground barrier checking the sub-surface flow thus damming back a large underground supply of water. The writer has suggested to Government that this area should be prospected as he has great hopes that it may cheaply solve the Raichur town water supply. It is the existence of such bands of highly absorbent material that may quite upset the calculations of a water prospector. Normally it would be in the lower slopes of a valley that the greatest volume of underground water would naturally be expected. It has been hinted before that this is not always the case, for as in the case of Vedvatti, east of Raichur, the upper slopes of the valley are underlaid with highly decomposed rock holding large potential supplies of water, whereas the lower slopes are underlaid with fine grained impermeable grey gneiss, whose only yield of water can come from its joints, which in that class of rock are relatively small and rare.

The following description given by Ellis and Lee in U. S. W. S. P. No. 446, is very applicable to the granitoid gneissic rocks of Hyderabad State :—

"The most important source of ground water in the highland area is the residuum or, as it is commonly called, the 'decomposed granite,' (*mooram*) which covers the bedrocks in all the highland basins and occurs more or less generally throughout the area. This material consists of small lumps or grains of the original crystalline rocks that have been disintegrated by the removal or alteration of some of their mineral constituents. The disintegration is most complete at the surface, where in many places the rock has been completely reduced to soil, and it decreases gradually from the surface downward until, at depths ranging from 3 feet to more than 100 feet, it merges with thoroughly indurated

rock. Granite is one of the most easily altered crystalline rocks and is the most prevalent rock in the area, so that by far the largest part of the residuum is derived from granite.

"The porosity of the residuum varies greatly, as it depends upon the degree of disintegration, which is subject to wide variations, both vertically and horizontally. In one place, for example, a well may be easily dug with a pick and shovel to a depth of 50 feet or more, whereas in another place only a few rods distant blasting may be necessary at a depth of 15 to 20 feet. But, as a rule, the residuum is sufficiently porous and disintegrated to afford storage for water. There are many rock basins which are nearly watertight and contain considerable disintegrated material in which water is stored. Groundwater may be drained from a large area by sinking wells through the decomposed rock and digging tunnels or boring holes at right angles to the slope of the surface.

"The yield of wells has been found to range under different conditions from very small quantities to as much as 150 gallons per minute. The smallest yields are obtained from wells without laterals, in shallow decomposed rock or in unaltered rock, on upper slopes or in small ravines, or in other places where conditions are not favourable for large absorption, the largest yields are obtained from wells that penetrate residuum of considerable depth, that are provided with lateral tunnels and auger holes, and that are situated in valleys irrigated with water from an outside source. In general, it may be said that the specific capacity of the best wells in residuum is about 8 gallons a minute per foot of drawdown,* that for many wells it is as low as 1 gallon a minute per foot of drawdown, and that for the poorest wells it is much less than 1 gallon."

F. G. Clapp, in U. S. Geol: Sur: Water-supply Paper 223, endeavoured to obtain some data as to the success of wells in crystalline rocks. He found that, in the case of bored wells drilled in the Maine granites, 87 per cent. were successful, but, out of 72 producing wells, only 3 yielded over 50 gallons per minute. The data also shows that out of 40 wells, drilled to a depth of between 50 and 100 ft., 95 per cent. were successful, but the percentage of successful wells decreased with depth.

From the returns of the Mysore Well Boring Section of the Department of Industries and Commerce for 1929-30, we find the average yield from 22 holes drilled to an average depth of 107 ft. was 459 gallons per hour. This

* 'Draw-down.' For explanation, see Testing the yield of wells. p. 149:

excludes the failures. If the three holes giving over 1,000 gallons are excluded as a fair set-off, the average yield per hole is 298 gallons per hour.

Below I give a table from du Toit's Bore-hole water-supply in the Union of South Africa, Proc. S. A. Soc. Civ. Eng. 1928, which tells the same tale:—

TABLE VII.

TABULAR LIST OF MEANS

Area	No. of holes	Total depth	Depth of water	Water rises to	Daily foot-age	Annual rainfall	Yield in gallons per diem	Percent-age of failures
Old Granite.								
Pretoria Jo'burg ..	62	136′	70′	37′	6·5′	28″	20,000	14
Northern Transvaal ..	497	156′	112′	73′	6·7′	21″	21,500	25
Rustenburg S-Western.	130	201′	170′	133′	5·7′	22″	16,900	50
Transvaal ..	404	122′	85′	46′	8·0′	21″	25,600	10
Mafeking ..	202	166′	120′	95′	9·0′	19″	19,900	35
Vryburg	136	158′	119′	101′	9·4′	17″	15,750	27
Van Rhynsdorp. ..	16	184′	143′	116′	6·4′	5″	4,200	31
Schist in the Old Granite								
Pretoria Jo'burg ..	15	130′	85′	32′	8·5′	30″	47,500	..
Kraaipan system								
Mafeking ..	35	178′	132′	109′	10·3′	18″	11,500	37

All these facts show that, as joints in crystalline rock are very irregular and their size and frequency of occurrence decreases with depth, the chances of a bore-hole striking a sufficient number of joints to give a town, or

village water-supply in this class of rock are very problematic, and no geological theorizing will assist the water finder.

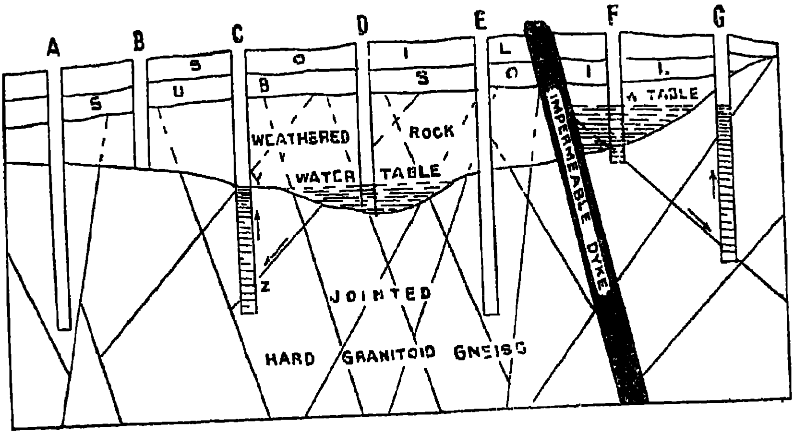


Fig. 12, above illustrates the possibilities of finding water in crystalline rocks. It will be seen that A, strikes no fissures and is a barren well or bore. B, will have poor recuperation, though near to D, whose recuperation is good having entered a hollow in the decomposed rocks, C, would be dry till joint Z was struck when water would rise to Y. Wells F and G on the rise side of the dyke obtain ample supplies. G, gives sub-artesian effects but E, is dry.

Effect of dykes or impermeable bars.

If a highly schistose inclined gneiss is traversed on its "dip side" by a dyke and the surface is formed of clay or laterite both of which are impervious, the water collects underground on the rise side of the dyke. Here a well or a bore-hole is likely to meet with artesian, or semi-artesian conditions. *Vide* Fig. 13 below. The best instance the writer knows of, to illustrate this point, is the well in the Station Yard at Ghatkaser, N. S. Rly., mile 12 from Secunderabad. This well has been accidentally sunk on the "rise" side of a cross dyke, and it actually overflows after heavy rains, whereas the well sunk in the

garden, but a hundred yards to the west on the other side of the dyke, is dry. The Station Yard well, however, goes dry in summer.

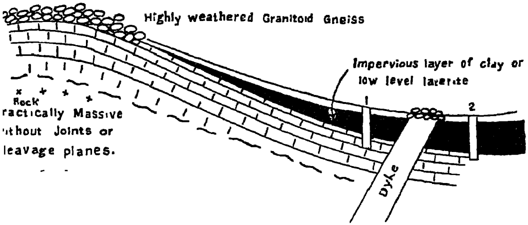


Fig. 13 —No. 1 well above would be prolific and certainly overflow after rains, whereas No. 2 would be useless.

The well at Mahbubnagar was laid out to tap the underground water lying stanked back against a dyke which forms an impermeable underground dam across a valley north of the town.* The Nizam's State Railway sank a successful well to supply Lallaguda Workshops, following out the same conditions. These conditions are far from being rare, if looked for, but, save in the case of Mahbubnagar, it is not often that they are to be found so ideally placed as to be used for town supply With the prospect of starting an Agricultural Well Sinking Department, where the geologist or engineer is not tied down to any special area, a lot of these large underground supplies can be tapped.

Schists.†

The Dharwar schists for the most part throughout the Dominions lie at a high angle. They are geologically

* The writer regrets, that after his departure for the War, his orders to increase the capacity of the original well by tunnels, were not carried out. He is not responsible for its present dimensions.

† For full description of Dharwar Schists see Vol. I, pt. 1; Vol. II pt. 1 of this Journal.

named according to their prevalent ferro-magnesian mineral. Thus we have mica schists, talc schists, the former being recognisable by the mica and the latter by talc which is characterised by its greasy feel. Hornblende schists and chlorite schists, the first harder and of a darker bluish green than the second, are sometimes called greenstone schists. Another very noticeable schist, forming large rolling hillocks in the Raichur and Nirmal Districts, is the hæmatitic schists which are recognisable from their banded appearance with parallel streaks of shining specular iron, and are frequently highly magnetic. All these schists have undergone intense metamorphism and are frequently found highly contorted and bent. On account of their pronounced schistosity a good volume of water is found in their cleavages and fractures They may be considered as a certain source of water at a shallow depth.

Dykes and quartz veins and other impervious intrusive rocks.

The whole of the crystalline rocks are traversed by frequent dolerite and diorite dykes, some of them of great length cutting clean through the country and owing to their superior hardness, forming long ridges which, stand out conspicuously in the landscape. They are more or less wall-like masses of rock, formed by the cooling and hardening of molten rock material forced upwards into fissures from the underlying magma on which the earth's crust rests. They are of different geological ages, and in some cases the newer ones can be found intersecting the older ones. Although often highly decomposed on the surface into rusty coloured rounded boulders, yet below, at a shallow depth, they frequently become solid impervious bars and alter the level of the entire water-table of the surrounding country.* Very frequently, owing to their tremendous heat at the time of formation, they are found to have entirely altered the rocks forming their flanks, by contact metamorphism which has assisted in making a further impervious barrier to the passage of water. See Photo Plate

* See Well. F. Fig. 12 p. 76.

IV, Fig 2. Generally wide dykes will be found coarse in crystalline structure though finer in texture at the edges, sometimes becoming schistose in character. Care should be taken not to confuse these with ordinary schists referred to above. Narrow and thin dykes are generally fine-grained. In some instances dykes have decomposed to a considerable depth. Sometimes in their rise to the surface they force their way horizontally into the invaded country. Such horizontal intrusions are called sills and often introduce large bodies of water. Such a sill was met with by the Deccan Development Co., when sinking the Holman shaft at Manglur Mine, north of (Beydur) Surapur, Gulbarga Subah. At this intersection point of the dyke, at about 500 feet, the shaft was flooded with copious water and about 7,500 gallons per hour had to be dealt with.

In the granitoid gneissic area of the State the country is frequently intersected by dykes running in several directions, though north-westerly and south-easterly, and easterly and westerly courses are the most common directions. A very good example of such conditions can be seen from the top of Bhongir Fort. If the country is thus intersected with dykes, when choosing the site for a well and relying on its property of impounding underground water, a careful survey must first be made of the surrounding country to see that there is no other cross dyke on the rise side which has intercepted the underflow, and thus limits the catchment area.

Quartz veins varying from an inch up to many feet in width are a very common occurrence in the crystalline area. A well known example to all "*mulkis*" is the big quartz reef which crosses the Hyderabad-Sungareddy road, west of Kotakpully, from which the glass works take their silica. These reefs, like dykes, have the effect of completely dividing the water-level of the country and, where they are found to traverse valleys, act as sub-surface dams and store up large quantities of underground water.

Besides dykes and quartz veins, many other intrusive rocks, such as *pegmatites* and *aplites*,* may act as under-

* Coarse and fine-grained acidic varieties of the granite family.

ground barriers and their intrusion may have shattered the gneiss, or granite at their junction, increasing the joints and fissures and thereby increasing its water carrying capacity. In the Raichur District the pegmatites frequently yield saline water, but the writer has not yet heard of this occurring throughout the State. Observations on this point will be welcome.

Taking the information gained from wells sunk all over 4,000 sq. miles in the crystalline complex of the Raichur District the following data is gained.

Before reading these figures it must be remembered that these wells had to be sunk as near as possible to existing villages, which very often, as a precautionary measure in the days of the old Mahratta raids, are perched up on the highest land available. So, in most cases the Well Sinking Department had no scope for selection of the most suitable site, but was tied down to find sufficient water-supply within a very limited area.

TABLE VIII.

Average depth of 383 wells sunk in granitoid gneiss and schistose area	30 ft.
Average depth of soil	15 ft.
Average depth of decomposed rock	7 ft.
Average depth of rock	8 ft.
Average level of water-table	23 ft.
Average recuperation	500 gls. per hour.

Out of 383 wells 39 wells were sunk in the Dharwar Schist area.

Springs are not uncommon in the Raichur District, especially at the junction of the Dharwars and the newer gneisses. Typical examples are to be seen at Pamankallur, Yerdoni and Hira. (*Vide* Geological Map). Advantage could be taken of these conditions to sink wells for large irrigation schemes, if only the local inhabitant could be shown the advantages to be gained by judicious expenditure of capital.

du Toit finds in South Africa, what is frequently noticed in this State, *viz.* that rocks in areas of low rainfall frequently yield better supplies than those in areas of good rainfall. This may be accounted for by the fact that in arid regions the rocks are well exposed and only covered with a thin porous layer of soil, so that the occasional rains can easily penetrate and sink underground. On the other hand, in regions of higher rainfall, the rocks may be concealed under clayey decomposition products which hinder infiltration into the underground crevices. This latter condition is frequently found under extensive areas of black cotton-soil. This class of soil not only acts as a macintosh, but, at its junction with the unaltered gneiss, a highly impervious formation of yellow calcareous matter is found developed which practically prevents underground drainage. There is great fear, if such areas are subjected to heavy irrigation, that owing to lack of underground drainage the lands may become sour, especially in those localities where underground water is saline. (See Journal, Hyd. Geol. Sur. Vol. II, Pt. i).

Largest underground water-supply not always found in areas of highest rainfall.

The water from gneissic country is invariably hard; the average of 313 samples taken from wells sunk in Raichur District giving 48·5 degrees. This average hardly represents the case, for the total hardness in the samples varies between 4 and 338 degrees. The hardness of the water is due to the presence of calcium and magnesium salts. At the site of the springs at Pamankallur, Yerdoni and Hira, referred to above, at the junction of the Dharwars and newer gneisses, large beds of kankar have formed. At Pamankallur mile 10 from Lingsugur, on the Lingsugur-Raichur road, the bed is 25 ft. thick. Such beds of kankar are common throughout the crystalline area.

Chemical composition of water from crystalline rocks.

The following statement shows the average comparative total hardness and salinity (as total chlorine) of waters

in relation to the nature of the rock met with in wells in the Raichur Doab. One degree of hardness corresponds to one part of lime or its equivalent in 100,000 parts of water.

TABLE IX.

	Average total hardness	Range in hardness variations	Average total chlorine	Range in chlorine variation
	Degree.	Degree.	Per cent.	Per cent.
(*a*) Hornblende Schist average(of 39 samples) ..	47	24 to 89	0·033	0·004 to 0·096
(*b*) Homogeneous,spotted or banded gray gneiss, (average of 10 samples) ..	35	24 to 59	0·019	0·010 to 0·036
(*c*) Binary acidic pink series, pegmatites and red syenite (average of 40 samples).. ..	43	6 to 164	0·091	0·004 to 0·352

NOTE :—It is thus seen that the water derived (1) from (*c*) is characterised by maximum salinity and medium hardness with widest variation, (2) from (*a*) by medium salinity and maximum hardness with medium variations, and (3) from (*b*) by minimum salinity and minimum hardness with minimum variations.

TABLE X.

The following statement of analyses shows the great variation in the quality of brines obtained from various localities in the Raichur Doab. Samples 1, 2 and 3 are from bore-holes within a distance of about 3 miles along the same nullah, within a few hundred yards of each other—

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
Anhydrous. Solids in 100 ccs. ..	1·2034	1·1714	0·6369	1·673	1·508	2·135	0·654	1·435	0·907	0·863	2·009	0·786
1. NaCl ..	59·1	47·61	25·71	47·16	54·40	44·19	14·41	28·15	24·36	43·33	60·52	37·91
2. $MgCl_2$ ..	3·26	16·02	..	..	1·70	21·13	14·4	..	10·69	..	..	..
3. $CaCl_2$ ..	..	7·31	..	..	..	11·95	5·42	..	32·96	..	..	..
4. Na_2SO_4 ..	..	..	61·0	9·02	..	..	..	44·69	..	6·25	17·81	42·11
5. $MgSO_4$ ..	14·48	..	..	26·60	23·01	..	..	12·54	..	16·8	9·0	11·45
6. $CaSO_4$ ..	21·23	26·82	..	15·84	18·60	21·55	16·79	11·14	31·42	31·51	12·25	00·89
7. Na_2CO_3 ..	..	..	6·51	..	..	..	..	..	..	..	..	..
8. $MgCO_3$ ..	..	..	3·29	..	..	..	..	..	..	..	..	..
9. $CaCO_3$ ..	1·93	2·21	3·45	1·37	2·27	1·17	6·66	1·47	0·55	2·08	0·5	73·6
10. Nitrates ..	..	..	..	..	..	..	42·93	..	..	..	..	..
Total ..	100·00	00·07	99·96	99·99	99·98	99·99	100·61	99·99	99·98	99·97	100·08	100·00

Saline water.

In the Raichur and Surapur areas there are large areas where the crystalline rocks yield water which is undrinkable owing to its salinity. This comes from deep-seated springs and not, as it was supposed, from absorption of salts by infiltration of the rain water through the black cotton-soil.

The total saline contents varies up to 2·5° B. As far as the investigations of the Geological Survey Department have gone, these saline areas occur in close proximity to the junction of the old Dharwar schists, and the newer gneisses, and are especially associated with a *dark red syenite* rock, one of the varieties of the crystalline complex, veined with a green mineral called *pistacite*, (a silicate of alumina, iron and lime), called so owing to its colour resembling that of pistachio nuts. Another rock associated with the occurrence of saline water, is a rock called pegmatite. Pegmatite is a variety of granite, usually of very coarse crystallization of quartz, feldspar and mica with frequent rarer minerals, occurring in dykes or veins in the granitoid gneiss. Pegmatites are igneous in origin and are found in dykes, sheets, pipes, and irregular masses.

Hoping that this salinity might only be a surface phenomenon and better water might be found deeper, tests were made but without success.

These two rocks in these two districts mentioned above, are liable to hold saline water, which we believe comes from deep seated springs. These rocks are known to occur all through the crystalline rocks of the Dominions, but whether in other areas they yield saline water is not yet known. As far as our observations have gone it appears that these saline springs only occur when these rocks are in association with the Dharwars. The igneous rocks, according to Clarke's calculation average only 0·07 per cent. of chlorine. So, it is not easy to account for the high percentages shown in Table IX and Table X opposite, unless the theory of dying volcanic action is introduced.* Any information on this subject

For fuller details I must refer the reader to Vol II part 1 of this Journal.

of saline water in the State will be gratefully acknowledged by the Geological Survey Department.

Search for drinkable water in saline areas.

The location of drinkable water in the saline areas is one of extraordinary difficulty. First, the rocks are for the most part masked with a considerable depth of soil, so in consequence, the choice of site for a bore or trial pit is a matter of entire guesswork. Secondly, even if drinkable water is struck in a bore, there is no certainty that a well sunk at that site will not cut other saline springs and the resulting water be thus rendered undrinkable. No rule seems to apply. Wells have been sunk not 30 feet from existing sweet water wells which have turned out saline and undrinkable. In some cases drinkable wells in saline areas have been sunk with apparent success. Owing to the rush to draw this water, overdrawing has resulted. The *cone of exhaustion** around the well being too great, saline water from some neighbouring crevice has filtered into the well, making the well finally useless for drinking purposes.

The writer came to the conclusion that some unused brackish wells in the Sindhnur taluq, beautifully lined with ashlar dressed stone and decorated with carvings, must originally have supplied drinkable water. In five instances these wells were pumped dry and cleaned out before the rains and several times pumped out again so as to allow the percolation from the monsoon to wash the accumulated salts out from the cone around the well. Each fresh recuperation was tested chemically. The result on the whole was satisfactory as three wells out of the five now supply drinkable water. In these three cases there is little doubt that during one of the concurrent years of drought which affect the Raichur District, the water owing to extensive evaporation and insufficient recuperation had become unpalatable, and the villagers had stopped drinking it, using the water for washing, etc. Continued years of insufficient rain had increased the trouble, so that at

* For definition of the term see pp. 147 & 148.

last the water in the well, when first inspected, had gained a high percentage of salinity.

The wells in Raichur and other towns, which are now reported as saline and which records show were once drinkable, might be treated with advantage in the same manner.

The only feasible remedy for obtaining fresh water in saline areas is by catching the fresh rain water in *sand traps* or what are called elsewhere *sub-surface dams*; these are more fully explained on page 160 and Plates, X&XI. For further reference see Annual Reports of the Well Sinking Department for 1338, 1339, and 1340 Fasli (1928-29, 1929-30, 1930-31).

Pre-Cambrian and Sedimentary rocks.

For the purpose of this pamphlet the age of rocks is of no consequence. But, as we have seen above, it is their permeability and structure that affect us. To save space it is as well to group together for examination these two series of rocks of widely varying age.

Pre-Cambrian. (Unfossiliferous).

The so-called Lower Vindhyans are represented in the Dominions by the unfossiliferous rocks exposed in the valley of the Bhima and Krishna rivers, at Cuddapah, at Kurnool, around Sullavai, in the Pakhal Taluq and in the Penganga valley, each series being called after those towns and rivers.

The Bhima Series which, Bruce Foote calculates has a total depth of 10,000 feet, is represented in the Dominions as under :—

Very compact " waxy " limestones, " Talikot " beds, grey, cream-coloured, blue, purple, pink &c., with some shaley beds, some beds are " lithographic "	80 ft.
Purple, red, drab and dark-green shales with thin calcareous flags or shales near the top. Locally a gritty purple quartzite underlies the limestone, especially in the most westerly sections	80 ft.—100 ft.

Quartzites, sandstones and conglomerates ..	..5 ft.—60 ft.

The unfossiliferous rocks known as the Cuddapahs and the Kurnools are represented in the State along the bank of the Krishna river. In descending order the beds are as below.

Kurnool Series of the Vindhyan System of rocks	Limestones Shales Sandstones Conglomerates	1,200 ft.

Unconformity

Cuddapah System	Limestones Slates Quartzites Conglomerates	more than 20,000 ft.

The Pakhals have been subdivided as follows :—

1. Quartzites with a few slates .. 700 ft
2. Siliceous limestones .. 150 ft.
3. Clay slates and quartzites .. 500 ft.
4. Grey and fawn coloured siliceous limestones .. 300 ft.
5. A slaty band, with thick seams of quartzite sandstone .. 3,600 ft.

The Pakhal beds extend in a north-westerly direction to the Maner river, but in this region the rocks are less indurated, the shales more finely grained and the limestones less prominent.

The Penganga beds in the north-west of the Dominions have been identified by King with the Pakhals of the Maner valley, the main difference being that the limestones have a layer of ribbon jasper and are found resting directly on the gneiss, the bottom conglomerate bed being absent.

Besides these beds, the Kaladgi series of sandstones and conglomerates occur just within the boundary of the Dominions on the western edge of the Kushtagi

Taluq of the Raichur District, but their area is so very small that they hardly need a reference in this pamphlet.

Along the lines of faults in all these rocks very large water-supplies are available. To give two instances, the fault at Nagai, in the Bhima series near Chittapur Station N. S. Ry., gives a large perennial flow. At Mudenur and Hensgi in the Surapur Taluq springs irrigated 124 and 33 acres respectively. Owing to shortage of rain during last 12 years these springs now no longer flow.

As a whole these rocks give good water supplies.

Salinity.

At Wadi in the Bhima Series and in Alampur the sedimentaries give saline water. Some of the salinity most probably is due to the salts leached out of the soil, though there is a possibility that the chlorine contents may arise from the connate water derived from the Purana sea postulated by Sir Thomas Holland. The writer does not know whether any attempt has been made to pierce the sedimentaries at Wadi, but Mr. Ernest Wilkinson of the Nizam's State Railways tells the writer that this has been successfully done on the Hyderabad-Kurnool line, and sweet water has been met in the underlying metamorphics. This discovery is of great importance.

Sedimentary. (Fossiliferous).

The Middle and Lower Gondwanas are represented by a series of thick beds of alternating fossiliferous sandstones and shales, sandstones being in the preponderance.

The beds below the coal measures, known as the Talchir beds, consists of shales and sandstones with boulder beds towards the base, the result of some previous ice age.

As far as water finding goes, both these series of rocks present no difficulty. The water derived from wells and bore-holes drilled in the Talchirs is sometimes very slightly brackish, but on the whole all these rocks supply beautiful potable water, though naturally in the limestone districts the water tends to be hard.

When boring in the Barakar series of rocks, on several occasions artesian conditions were met with, but in no quantity and with no great head. In most instances the flow ceased when the casing pipes were removed. Although the author never drilled with the idea of obtaining artesian water, the possibility should not be lost sight of.

During the sinking of the Kothapet shafts by the Singareni Collieries Co., 60,000 gallons per day were met with. Mr. Andrews the General Manager writes :—"The water was not brought in by faults and was first met with at, approximately, the depth of 100 ft., the quantity increasing regularly up to a depth of 400 feet. In several places, between 100 and 400 feet, large inflows of water occurred through crevices or natural openings in the strata, the largest being about 2 ft. in width by 8 to 10 ft. in height."

Deccan Trap and Laterite.

The area shown on the attached map, marked Deccan Trap, is the remains of what was once a far greater spread of vulcanic lava. Through the course of geological ages it has been enormously worn away, for traces of it are to be found as far south-east as Rajamundry, showing that once probably the whole of the Nizam's Dominions was covered with this vulcanic lava. Stretching as it did at one time from Sind, it must have once covered an area of at least half a million square miles. Even to-day, in its denuded condition, the present existing lava spread of Deccan Trap comprises 200,000 square miles and is the greatest known spread of vulcanic lava in the world. Of the above area 32,000 square miles lie within the State limits. For how many millions of years this vulcanic activity continued can only be conjectured, though it must have been enormous as the greatest thickness of these vulcanic lavas is now nearly 10,000 ft.

During the era frequent periods of extended quiescence occurred. These periods were of such a great

length that the molten lava had not only time to cool, but vegetation started again, pools and lakes were formed, normal pond life with its fishes, frogs and vegetation existed, and insects flew over the ponds. All this we know from the fossil remains. During this period of quiescence disintegration of the surrounding area was in progress through rain and other normal causes, and partially filled the lakes and pools with mud, burying the discarded shells of the molluscs, dead frogs and fishes just as it happens in a big tank to-day.

The study of these rocks shows that suddenly the scene changed, and with awful swiftness, perhaps without warning, another vulcanic outburst occurred, and similarly, as happened in Guatemala in 1929, a fresh wave of red hot, highly liquid lava, rolled over the landscape obliterating and burying everything beneath its terrible onrush. From geology we also learn that the process of vulcanic outburst at times changed from the welling-out of highly liquid molten lava from vents, and for a period vast masses of ashes, and scoriæ were ejected, which we now find as local interbedded ash-beds between the layers of ancient vulcanic lava.

These periods of quiescence, and periods when ash instead of lava was ejected, as far as our geological observations have shown, occurred locally at intervals throughout the whole periods of vulcanic activity. However, these periods were not apparently simultaneous over the whole area, so that the occurrence of these ash-beds and interbedded rocks occur in a more or less haphazard manner, and the lateral spread of these beds at times is only a few miles in extent. The overlying Trap rock, throughout, is more or less similar, save as regards the thickness of the layers and the amount of weathering that certain layers underwent before being covered by the succeeding flows. The examination of the different exposed lava layers, unless more carefully studied, at present is of no help in locating the existence of these highly decomposed layers which are the great water-carriers of this rock series.

I give below a general section of the Deccan Trap :--

	Lava flows with numerous ash-beds.
Upper Traps 1,500 feet.	Sedimentary inter-trappean beds of Bombay with large number of fossil vertebrata, and molluscan shells.
Middle Traps 4,000 feet.	Lavas and ash-beds forming the thickest part of the series. No fossiliferous inter-trappean beds.
Lower Traps 500 feet.	Lavas with few ash-beds. Fossiliferous inter-trappean beds.

Slight Unconformity.

Lameta or Infra-Trappean beds, and older rocks over which the Trap flowed.

It is as well to amplify this section as far as our limited knowledge goes.

Mr. Wadia in his " Geology of India, " gives the following type section through a portion of the basalts, but unfortunately does not give the locality from which the section was taken. It shows the relations of the Traps to the sedimentary intercalations as well as the infra-trappean Lametas :—

1. Bedded basalts, thick.
2. Cherty beds, lydites, with fossils. 5 ft.
3. Bedded basalts, very thick.
4. Impure limestone, stratified tuffs, with fossils, 7 ft.
5. Bedded basalts, thick.
6. Siliceous limestones with sandstones (Lametas), 20 ft.

So much for the technical description of the rocks with which we have to deal in Marathwara districts.

A casual examination of these layers of lava, exposed in cuttings and escarpments, shows that they have cooled and weathered in very distinctive and different ways.

But, before any start is made in the examination of these lava flows, the reader must more fully realize the vulcanic process, and it must be the writer's endeavour to explain the probable sequence of events so clearly that the reader can practically visualize the series of events.

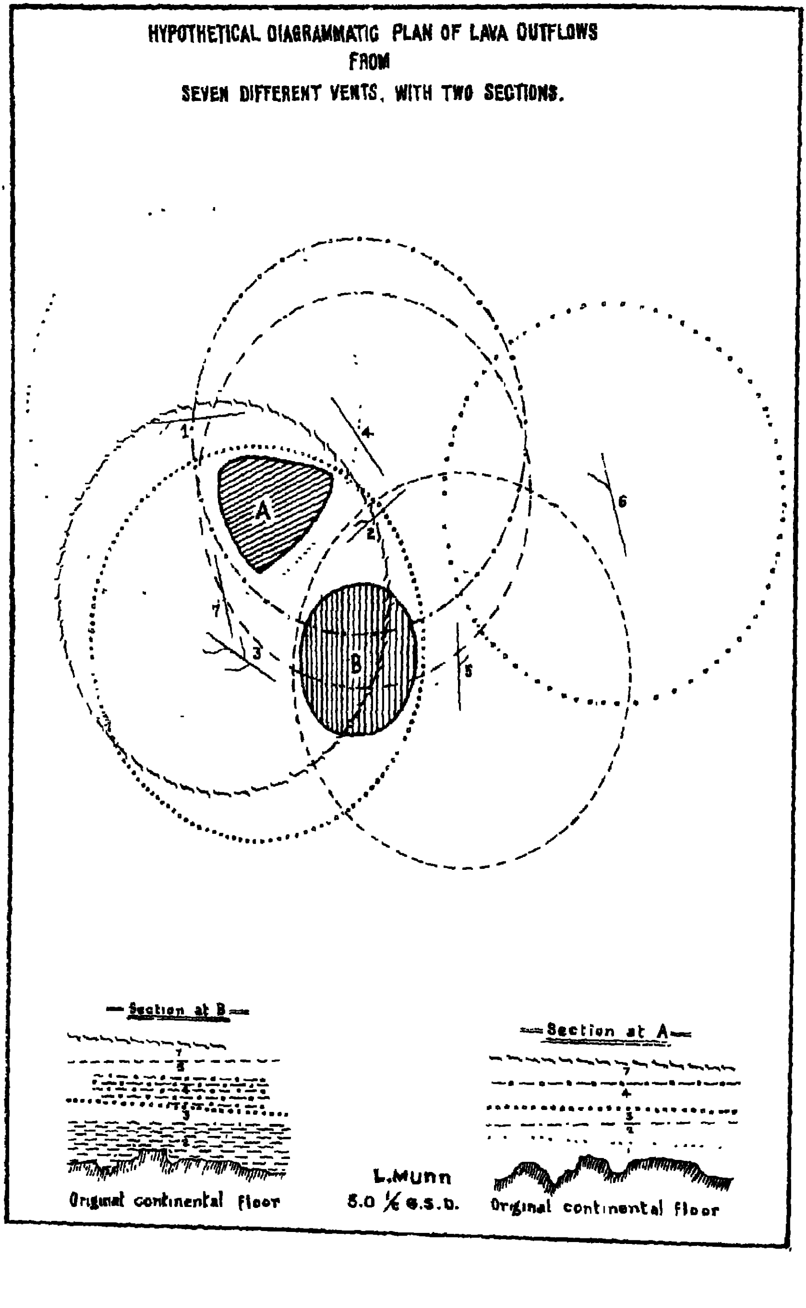
The reader must attempt to imagine huge, long, deep rents suddenly forming in the old continental crust of Gondwanaland so deep as to give release to the underlying magma, the compressed molten lava on which our continents rest, or float. The pressure thus released would allow this molten matter to well-up to the surface at a temperature of some 1200°C and pour out like white hot fluid metal over the surrounding country. Some cause stops the flow of lava, and, for a period, just as occurs to-day in the vulcanic areas of the world, *e.g.*, in Japan, and at Vesuvius and Etna in Europe, a period of quiescence of unknown and uncertain length follows.

The thickness of the hot lava that has flowed out from the vent will vary in each eruption according to its magnitude and duration. The lava layer will cool rapidly and, owing to its nature, will immediately start to contract and become fissured. This process would be specially assisted if the overheated surface were suddenly quenched and chilled by heavy downpours of rain, which frequently accompanies such vulcanic disturbances. The period that elapses between the first and the following outflows decides the amount of surface disintegration and denudation, that each special individual layer undergoes.

For reasons, not yet fully explained each succeeding outflow of white hot magma is not always of the same chemical composition and, as stated above, probably for this reason, besides others, their structure, after cooling owing to sudden contraction, assumes many different aspects.

The reader must clearly grasp the fact that these outpourings of molten lava did not always start from the selfsame vent, nor even from the same locality and, at times perhaps, several vents were functioning at the same time. This will account for the reason why in one area we may find the sequence in the order of lava layers consistent throughout, whereas in another area, but a short distance away, the sequence may be entirely changed, though perhaps having some recognizable layers in common.

PLATE. VII



HYPOTHETICAL DIAGRAMMATIC PLAN OF LAVA OUTFLOWS
FROM
SEVEN DIFFERENT VENTS, WITH TWO SECTIONS.
A
B
1
2
3
4
5
6
7
Section at B
Original continental floor
Section at A
Original continental floor
L. Munn
S.O. ½ G.S.D.

In Plate VII, the writer gives a hypothetical, diagrammatic plan of a series of supposed lava outflows from 7 vents, each overlapping the other as probably might have occurred. The reader may take the scale of plan at anything from 10 to 50 miles per inch, and understand that the circular areas of outflow have no specific meaning, but are purely diagrammatic. It will be seen from the plan and section that, whereas all the traps in area A, follow an exact sequence, and do not vary except perhaps in thickness, the same sequence can occur in no other area on the plan. The section in area "A" is totally different from that of area "B."

Underground water in Deccan Trap areas.

The above resume of the geology of the Deccan Traps has been given, to enable the general reader to appreciate the relation of these lava-flows in their bearing on the underground water resources. The amount of money wasted in unsuccessful attempts at the excavation of wells in the Trap-area through ignorance of the geological knowledge of the formation is enormous. Even technical departments do not seem to realize the absolute necessity of understanding the geology of the horizon in which operations are carried on, while others rely on the uncertain vagaries of a water diviner's magic wand, or the oscillations of a needle sporadically affected by an unknown cause.

Distribution of underground water in Traps not irregular.

A lay observer is generally perplexed at the fact that in a Trappean area, the distribution of underground water is apparently irregular and intriguing. He may find, for instance, copious water-supply at the 1800 ft. contour, but, within a short distance, a lower level may be quite barren. Such observations run contrary to what his notions of the nature and distribution of underground water should be, and he trusts to chance and water-diviners when he wants to excavate a well.

Method of study.

The distribution of underground water in a Trap area is really quite regular and can be appreciated and understood by a man of average

intelligence, if only careful observation is made. For the purpose, an examination of good sections exposed along nullahs or ghat roads has to be initially made. Then detailed notes on all the water levels in wells occurring in this zone have to be taken, and a correlation of the geological formations with the distribution of underground water generally supplies a solution to the problem

Traversing the Trap-area at places where good sections are exposed, it may be seen that they consist of a number of horizontal layers, the contact between successive layers being quite sharp. Each of the layers is more or less of uniform thickness and physical character over a large area. One layer may weather into exfoliating boulders, another may be seen to give rise to columnar jointing, while a third may have altered into pink and red mooram-like material, loose or compact, with or without *zeolite** and other secondary minerals, with an occasional remnant of pumice, or sponge-like vesicular rock. We need not go into the details here, but it may be mentioned that these differences in the nature of weathering of the successive layers are mainly due to the original physical conditions attending each extrusion, such as the temperature of the lava, the rate of its cooling, the amount of vapours and gases associated with the flow, and to a minor extent, to the slight difference in their chemical constitution.

Traps from 2,200 ft. to 1,650 ft. levels and their classification.

The general result of a study of the Traps carried out under the writer's directions in parts of Osmanabad District may be briefly reviewed here, with the object of illustrating how the problem may be tackled in a Trap area. The writer first of all drew some rough correlations of the successive layers during a flying tour through the Osmanabad District and on his return, detailed Dr. Mahadevan, his Assistant Superintendent, Geological Survey Department, to investigate his

* Secondary minerals deposited by water infiltrations filling up cavities in the original lava.

hypotheses further. This has proved correct and the following details are extracted from Dr. Mahadevan's report. The country covered in the traverse is mainly from 1,650 to 2,200 ft. above mean sea-level.

An ideal vertical section, as deduced from observations in the neighbourhood of Naldrug, Tuljapur, Osmanabad, and Yedsi (see Plate IV), may be given here.

SECTION.*

(Highly water-bearing layers are in italics.)

2,200'—2,187 Jointed, weathered rock.
2,187'—2,160' *Red and pink zeolitic mooram-like layer.*
2,160'—2,142' Jointed compact rock.
2,142'—2,130' Exfoliating rock.
2,130'—2,117' Jointed compact rock.
2,117'—2,086' Decomposed rock, much jointed.
2,086'—2,070' *Hardened zeolitic mooram-like layer.*
2,070'—2,052' Bedded rock, highly decomposed along joints.
2,052'—2,033' Moderately compact, bedded rock.
2,033'—2,013' Hard compact rock.
2,013'—1,962' *Two layers of zeolitic mooram-like material.*
1,962'—1,943' Compact, typically exfoliating rock.
1,943'—1'930' Bedded rock, highly decomposed along joints.
1,930'—1,905' *Friable, mooram-like layer.*
1,905'—1,881' Compact, typically exfoliating rock.
1,881'—1,856' *Hardened zeolitic mooram-like layer.*
1,856'—1,840' Massive compact rock.
1,840'—1,822' Exfoliating rock in decomposed matrix.
1,822'—1,801' Mooram with stray exfoliating boulders.
1,801'—1,770' *Two layers of zeolitic mooram-like layer.*
1,770'—1,762' Highly jointed, non-exfoliating rock.
1,762'—1,749' Red mooram-like layer.
1,749'—1,740' Jointed bedded rock.
1,740'—1,728' Hard compact rock.
1,728'—1,715' Compact exfoliating rock.

* *Vide* Appendix IV, Plate XII for this and subsequent Sections in Osmanabad District.

1,715′—1,700′ Bedded jointed non-exfoliating rock, slightly weathered.

1,700′—1,680′ *Exfoliating rock, much weathered locally into mooram-like layer.*

1,680′—1,665′ *Much jointed decomposed rock and mooram-like layer.*

1,665′—1,652′ A highly bedded, non-exfoliating rock.

It may be seen from the above that some porous mooram-like layers lie interbedded between more compact lava beds. These compact strata are extensively jointed and act as a medium of percolation for rain water to lower levels. The mooram-like layers, on account of their comparatively loose texture and greater porosity, act as reservoirs for the water carried down to them. A thick bed of mooram has naturally a great capacity for retaining water. In certain zones, the mooram layer may be very thin, or even absent. In such cases, the more decomposed and jointed rock layer which lies above a compact flow may constitute the water-bearing strata. If the geological and physiographic conditions are thoroughly understood, perennial underground water can be located with a fair amount of certainty.

Correlation of underground water to successive flows.

Examination of various levels* in relation to the distribution of underground water, as deduced from a study of the well-sections, may illustrate some of the above conclusions. Between 2,100′ and 2,200′ levels, it is seen that the layer 2,160′—2,185′ consists of zeolitic mooram and the beds below this are more or less hard and compact. Actually the perennial wells in Osmanabad town are just at about 2,160′ level, and when a well has gone down to that depth, a good supply of water is assured. Ebrahim Sahib's irrigation well, which supplies a centrifugal pump driven by 12 h. p. engine, for irrigating a big garden, is excavated in zeolitic mooram-like earth, the bottom of the well being

* All levels in this paper are mean sea-levels deduced from nearest G. T. S., point.

at about 2,160′ level. The cool fresh water springs in cave No. 2 and cave No. 5, at Lena, a mile and a half north-west of Osmanabad, are at about this level, and they are said never to have dried up. The perennial wells at Chorkhali, 3 miles north-west of Yedsi, lie also between 2,165′ and 2,180′ levels.

The next thick layer of decomposed rock is between 2,070′ and 2108′. The perennial well in Siddheswar temple, a furlong east of Badagaon, near the 5th mile, 5th furlong stone on Osmanabad-Sholapur road, is between these levels. The well is said to meet the needs of thousands of pilgrims who muster there in the summer months for a jatra. The perennial spring by the side of Ramling temple, about a mile south-east of Ramling Flag Station, on the Barsi Light Railway is situated, in the zeolitic mooram layer at this level.

We see that below the 2,070′ level there are a few layers of compact rock, before the next porous strata is met with. A typical example of this is seen at Tuljapur where you have to penetrate through more than 60′ of rock before you can obtain a good permanent water supply. This accounts for the great scarcity of water experienced at Tuljapur. The perennial well which supplies water to Tuljapur in famine years lies about 6 furlongs east of Tuljapur. This is the Pachunda well owned by Mr. Hirachand Guzur. The well is 27′ deep and the bottom of the well is at about the 2,000′ level and shows zeolitic mooram in the exposed sides of the wall. From a reference to the above table, we see that the beds 1,962′—2,013′ consist of zeolitic mooram-like layer. In the above well it is claimed that, even in times of severe drought, enough supply is had for a centrifugal pump driven by an oil-engine. A good garden crop may be seen around this place. The Kapiltirth perennial spring, 2 miles, west of Osmanabad, just at the foot of the tableland, is enclosed by stone work and water flows from a channel irrigating several acres. This spring is in the same zeolitic mooram-like layer of the 2,000′ level.

Descending further, the next thick porous bed amidst the compact layers occurs between 1,856′ and 1,881′ levels. The perennial well (Gashle's well) at the foot of Tuljapur tableland, about a mile due south of the town, supports a betel-leaf garden and is dug in zeolitic mooram between these levels. Going lower still, it is seen that thick mooram beds occupy 1,770′—1,801′ levels. Actually we see that most of the flourishing and rich villages such as Sindphal, Dekhri and Mankeshwar thrive, as they happen to be situated between these levels, and tap this perennial underground water-supply. The big railway well close to Pangri watering station is also excavated to this level of mooram-like earth and yields a constant supply to the two oil-engine-driven pumps which are said to work alternately all the 24 hours.

The levels between 1,700′ and 1,770′ do not seem to be suitable for the storage of water and the few straggling villages situated between these levels suffer frequently from water-famine, but above 1,660′ up to 1,700′ may be seen some thriving centres. Some good wells near Malumbra and Babaji's well by the side of 20 miles, 2 furlongs stone on Osmanabad-Sholapur road, which supplies water to a pump driven by an oil-engine, are situated at these levels. The town of Barsi has a number of perennial wells for irrigation and domestic purposes between 1,700′ and 1,660′ levels.

From all the above examples, it may be seen that the distribution of underground water is intimately associated with the geological formations, and it can be determined from a knowledge of these, where, normally, to what mean sea-level we have to sink, to locate a good water-supply.

Limitations of Correlation.

It was pointed out in an earlier para page 92 dealing with the general geology of the Traps that a correlation which works in a particular region need not prove true over an adjacent area. This fact seems typified from the observations made around Parenda. The correlation of the beds to the water-bearing strata as observed in the Naldrug,

Tuljapur, Osmanabad and Barsi areas no longer holds good here. We at once see that amorphous silica is profusely developed here, giving rise to loamy soil in contrast to the black cotton-soil met with in the other area. The aquifer in this zone is generally in highly jointed rocks; the zeolitic mooram so profusely developed as water-bearing strata in the other area to the west and south-west does not occur here at the same corresponding levels; and it is very poorly developed between 1,700′ and 1,900′ levels. In Parenda the observer has not the advantage of the fine exposures which so greatly help him when examining the Osmanabad and Tuljapur Taluqs. The section below for the neighbourhood of Parenda has been deduced from exposures as seen in wells, and is tentative:—

1,900′—1,880′ Jointed rock, in parts exfoliating.
1,880′—1,865′ Much friable mooram-like layer.
1,865′—1,850′ Exfoliating rock.
1,850′—1,835′ Bedded, jointed rock.
1,835′—1,820′ Exfoliating rock.
1,820′—1,780′ Jointed, bedded rock.
1,780′—1,765′ Exfoliating layer.
1,765′—1,745′ Much jointed weathered type.
1,745′—1,724′ Much decomposed and jointed rock with agates etc.
1,724′—1,696′ Decomposed and jointed rock, in places, with zeolites.
1,696′—1,670′ Much weathered and decomposed rock.

The following are the important water-bearing strata in Parenda Taluq and, generally, it may be noted that villages thrive when situated above these levels.

Between 1670′ and 1700′ levels, a much jointed and weathered rock is the water-bearing strata. When wells are excavated below the weathered type, to the compact rock, a good water-supply is assured. Several wells in Parenda town exemplify the above statement.

At 1,750′, a much jointed, decomposed rock is the aquifer. The perennial wells in Kandari, 7 miles north of Parenda, are situated at this level.

Between 1,790′ and 1,825′ levels, highly weathered jointed rock contains a good quantity of water and several wells between these levels support garden crops. The perennial wells at Kukedgaon, Karala, Ekburzwadi and Vale, just north of Parenda, for example, are found to be sunk between 1,790′ and 1,825′ levels.

Within every area it is thus necessary to work out a local correlation between the various lava flows and the nature of distribution of the underground water-supply, and to determine the extent over which any particular correlation holds good. This study, though initially entailing much labour and careful observation, ultimately solves the riddle and saves much money and misdirected labour.

Dips and other structural features.

The correspondence of the sequence of the beds at nearly the same levels over a wide area shows that, regionally, the beds have very little dip in these formations. The Traps in Osmanabad District belong to the middle series of the flow and the beds show few structural peculiarities. They run for miles in monotonous horizontality. We have, however, to note that here and there, due purely to local causes, the beds may show disturbance. These peculiarities are mostly responsible for anomalies observed in such areas. They have to be carefully studied and taken into account when working the correlation at the places where they occur.

Sub-artesian effects.

Sometimes, sub-artesian effects are met with in the Trap area when a bore hole is drilled through the hard rock at the bottom of a well and a highly porous lower layer of Trap is encountered. A few such instances may be mentioned here.

It was learnt that at Boramani, 8 miles east of Sholapur, a 70′ bore from the bottom of a well 30′ ft. below ground-level resulted in a great increase of the recuperative power of the well. At Barsi, at the request of Mr. Desai of the Barsi Spinning and Weaving Mills, the writer examined his garden well where several 3″ bores, to a depth of 20′ from the

bottom of a well 25′ ft. deep, gave sufficient sub-artesian springs to supply a 4″ centrifugal pump running night and day, probably giving 10,000 gallons per hour. About 3 miles north of Parenda, between Khanapur and Bhonja, Mr. Nanchand Guzur drove a bore to a depth of 5′ below the bottom of his well, which was sunk in hard rock to the depth of 40′. He reports that a softer layer was encountered from which water rose in a jet 3′ above the level of the bottom of the well, and has since afforded copious supply for his intensive cultivation. His attempts to put a similar bore in an adjacent well also proved successful, but he had to go 9′ below the bottom of the well before he got adequate recuperation. At Latur, the Gunj well improved very much in recuperation when a bore was put down below the bottom of the well, but, this well being just below a tank, the pressure must be ascribed to that cause.

From an examination of the sections, it will be seen that there exist porous layers of decomposed Trap lying between relatively impervious layers of the compact Trap. These compact bands, however, are highly jointed vertically and do not present any serious obstacle to the downward passage of rain water from the catchment areas. In fact, these joints throughout may be full of water slowly percolating downwards into one of the highly decomposed layers which forms the underground reservoir. In these highly porous layers, the water gets more or less evenly distributed and, if tapped, receives recuperation from the overlying water in the jointed rocks. In the absence of any regular dips in these Traps, it is suggested, as a tentative hypothesis, that the sub-artesian effect met with in such places as the well of Mr. Guzur, 3 miles north of Parenda, must be accounted for by the mass pressure of water lying above in these innumerable joints and feeding the underground porous reservoir. If this be the correct interpretation of the phenomenon, it seems pretty certain that, whereas there may be sufficient hydrostatic pressure exerted by the water columns in these vertical joints to produce sub-artesian effects in a few instances, if hundreds of wells were sunk and

drilled to tap this porous layer, the amount of pressure derived from these joints would soon be exhausted.

To account for the semi-artesian effects in Mr. Guzur's well the possibility that the porous bed may, in some way, obtain its water through joints fed by some stream on a higher contour in the Bhum Jagir area must not be overlooked; in which case, the pressure being greater, a bigger number of wells could be supplied from the same source. It is for this reason the writer has strongly urged His Exalted Highness the Nizam's Government to take all possible steps for conserving the rainfall on the higher contours of all the areas, now marked as "Famine Zones," by means of small tanks and dams across nullahs, so to increase the underground percolation.

In other cases, such as at Boramani, near Sholapur and the well at Barsi Spinning Mills, until further investigation into this question is made, the existence of large local reservoirs, lying at a higher level than the collar of the well, must not be overlooked as the cause of water being struck under pressure. In the case of Latur, the Agricultural Department put down a bore at the bottom of Gunj well which lies just below the bund of a small kunta. The sub-artesian effect is, in this case, certainly due to this cause, as the pressure ceases when the kunta is dry.

Summary.

Our investigations prove that, at varying depths all over the Deccan Trap area, water lies in certain zones. The evidence supposed to have been obtained from "Patent Water Finders" is therefore, proved absolutely uninformative, because water at some depth or other exists throughout the region.

The question, whether it is preferable to deepen a village well, or put down a bore-hole to improve the village drinking water-supply, appears entirely dependent on what depth of hard rock has to be pierced before the next porous aquiferous layer is to be met with. Further, it is not all porous layers which will give sub-artesian effects; so, before boring is resorted to, this fact must be ascertained.

Enough study has now been made by the Geological Survey Department to prove that a correlation of the perennial water bearing zones with the more porous beds of the lavas in the Deccan Traps is quite a feasible proposition. Water-finding in a Trappean country can therefore be resolved to a rule of thumb, by careful levelling, once the correlation is known, instead of boring and sinking wells in the present haphazard manner, sometimes guided by a will-o'-the-wisp. Further, our geological investigation has upheld the writer's hypothesis that one rule of thumb will only apply within one certain area, but not necessarily 50 miles away. It will therefore be necessary to map out the correlation in zones, and such work will be of the utmost importance to the welfare of the inhabitants of Marathwara. Although the results from our first season's work in the Trap area have been highly gratifying, there is yet not only a big area to be closely examined but several problems are yet unsolved. It is hoped, to assist this Department in this most important investigation, that the officials of all departments, including the officers of His Exalted Highness the Nizam's Railway and private gentlemen, will aid us by keeping careful records of any well, boring or excavation they make and in the case of boring or well sinking, will kindly send us a return on the form given in Appendix I to this paper. For further investigation into this subject see Appendix IV, page 172.

Laterite.

In dealing with the Deccan Trap area another formation has to be also considered, which in many parts of the Marathwara overlies this Trap formation, namely the *Laterite*.

Laterite may be formed from any rock rich in iron and alumina ; the laterite referred to here is the result of subaerial alteration of the Deccan Trap lavas *in situ.* Suffice to say here, it is caused by an intermittent rainfall, combined with insufficient underground drainage.

This laterite forms a sort of clayey rock full of small holes (vesicules), and has the peculiarity of being soft when newly excavated, but, owing to its chemical

composition becomes hard and compact on exposure to the atmosphere.

It is not necessary to worry the reader with its chemical composition, but the writer would like him to note that, in places in India, it assumes the composition of bauxite, (aluminium oxide), and is of value, commercially, as a base for the electro production of aluminium, so that, if bore-holes or wells are put down in this rock, samples should be sent to the Geological Department for examination.

It is regretted that the laterite area within the Dominions has never yet been mapped, so the writer has no information to give on this subject. It is a piece of work which should be done, both from the mineralogical as well as the water-finding points of view.

Very often at the junction of the laterite and undecomposed Deccan Trap, large reservoirs of water are met with in a *lithomarge-like* rock or *bole*, a sort of transitional product. The laterite, being vesicular, holds water in its pores and is far from being impervious. However, owing to its nature of hardening when exposed to air, the writer is apt to conjecture that, old wells may become dry through the porosity of the rock, which existed when originally excavated, becoming imporous. This idea is given merely as a conjecture worthy of consideration, as the writer has had no chance of minutely studying condition of old wells in these rocks which once gave abundant supply of water, but have since gone dry.

The question of locating water, therefore, in the Deccan Trap area amounts to this.

The underground supplies will be obtained from the following main sources :—

(*a*) Seepage in the laterite zone.

(*b*) Probably bigger water-supply at the junction of laterite and undecomposed Trap.

(*c*) At each succeeding junction of the different layers of Deccan Trap.

(*d*) In the vesicular Traps and mooram-like layers occurring at unknown intervals, referred to above.

(*e*) In the inter-Trappean beds which are variously composed of impure limestones, cherty beds, lydite stone, and stratified tuffs in varying and uncertain thickness, and at unknown depths.
(*f*) The sporadically situated Ash-beds, which lie between the junction of the Trap layers at varying depths and uncertain thickness.
(*g*) At the junction of the Deccan Trap and the old land surface.
(*h*) Water from talus beds at the foot of Deccan Trap scarps, which is dealt with later in the pamphlet,

Pleistocene and Recent formations.

Alluvial deposits along river beds.

As far as the writer is aware, beyond damming back the rain water flowing down rivers and nullahs to form irrigation tanks of all sizes, no real engineering work has been done in the State as regards pumping water from the alluvial beds that frequently lie alongside the present courses of rivers. Many streams and rivers have changed their courses and their old beds are a great source of sub-surface water. Again, rivers have, in the course of forming their existing channels, worn their way through huge obstruction, (vide the gorges on the Krishna and Godavary rivers). Before these obstructions were cut through, in many places probably large lakes occurred in past geological time. The alluvials which once formed the beds of these lakes now form a huge underground water reservoir. The old alluvial beds on the north bank of the Krishna in Nalgonda Taluq, at Partial, the site of the old alluvial diamond mines,* are good examples.

The Well Sinking Department have not yet been called upon to deal with such sites for agricultural wells for irrigation problems, but, in the ordinary course of their work, have sunk several mass concrete cement wells as caissons

* See " A History of the Golconda Diamond Mines, " Journal, Hyd. Geol. Sur. Vol. I. pt. 1.

near big nullahs and streams, all of which have given a very high ratio of recuperation.

At Maski Dak Bungalow, Lingsugur Taluq, the first mass cement concrete caisson was sunk as a trial, by undercutting, 50 yards away from the north bank of the Maski nullah, in probably one of the old loops of the stream. This well is 8′ in diameter and 24′ deep and cannot be emptied by two power pumps each giving 2,000 gallons per hour; so this well gives ample water to irrigate 8 acres. Instances can be cited of many other wells sunk giving equal capacity and, in each instance, it is quite probable that even a higher recuperation could have been obtained by sinking the caisson deeper, should there have been any necessity.

Formation of alluvial beds.

The factors governing the work of erosion of an ordinary stream or river are not out of place here. The actual erosion may be divided under two heads *corrasion* and *corrosion*.

Water free from sediment does but little erosive work.

Corrasion.

The corrasive work of a stream is done by the sediment it carries. This consists of mineral matter ranging in size from fine clay to coarse stones, the grains acting like cutting tools.

The abrasive power of a stream therefore depends on the rock which forms its bed, its velocity and the load of sediment it carries. A swift, sediment-laden stream will cut its channel with comparative rapidity, but at a different rate in different kinds of rock bed; and, assuming the sides and bed of the channel be of equal resistance, the main erosive effort will be vertical. A slow moving stream cuts more actively laterally and does not deepen its valley much. As a result of this the sluggish stream is likely to develop alluvial flats.

Streams and rivers even with sufficient fall, frequently get dammed back owing to the flood waters being held back, due to the main stream being in high flood. The writer has seen the Wardha river, at Balharshah, rise 40′ in one night, simply for the reason that the flood water had no

exit, the Godavery being in full flood. This happens in all smaller streams, and frequently small nullahs leading into a big river, act as a backwater leading to the formation of alluvial flats.

Corrosion.

The work of solution or corrosion performed by a river is usually of secondary importance, except in limestone.

Depth of erosion.

A stream or river will carve out its bed vertically until it reaches sea-level or the level of some other body of water into which it flows. This is known as the *base level of erosion*. Deep pools known locally as *madgoos* have probably been scoured out by water-falls.

Once the base level has been reached the stream begins to cut laterally, broadening its valley, and starts to meander. This meandering leads to loops in which, during floods, the outside of the curve is being eroded and the internal side is undergoing a course of deposition. These spots are ideal for locating irrigation wells. Sometimes the course of a stream becomes absolutely horse-shoe in shape, when, subsequently the river may cut through the intervening space and straighten its course. These former channels will become silted up, but being still connected with the bed of the river by the bottom pebble beds, form large underground supplies of water. Thus even a small stream may form very extensive alluvial, found over a wide area, which only requires tapping to supply a very large quantity of sub-surface water.

Quality of Water.

All water, even carefully stored rain-water caught off a clean zinc roof, will never be found absolutely chemically pure. Water, whether derived from rivers, tanks, springs, wells or bore-holes, always contains solids and gaseous compounds in solution. It does not follow, on this account, that these waters are not excellent for drinking purposes.

Rain, in falling, absorbs gases, mostly carbon dioxide (CO_2) from the atmosphere and, in its passage underground, absorbs other gases and dissolves various salts, formed from decomposing minerals and organic matter derived from decomposing vegetation.

Origin of solids in underground water.

The waters obtained from different geological formations will widely differ; in fact, water from two wells in the same formation, only a little distance apart, can so vary that one may be drinkable, the other not.

The examination of Tables IX and X will show the large range of mineral ingredients that water may contain.

Mineral impurities.

Dr. J. C. Tresh has remarked that "the total amount of saline matter permissible in a drinking water depends, in a great measure, upon the nature of the salts. No hard and fast line can be drawn, but the best waters rarely contain more than 20 grains of mineral matter per gallon. When 100 grains is reached, the water becomes rather of a character of a '*mineral*' than a '*potable*' water."

The more common ingredients are:—

Calcium carbonate.	Magnesium chloride.
Calcium sulphate.	Sodium chloride.
Magnesium carbonate.	Sodium sulphate.
Magnesium sulphate (Epsom salts.)	Sodium carbonate.
	Silica.

Hardness of water is due to the presence of salts of lime and magnesium. According to the table of hardness, formulated by Dr. Thomas Clark and known as *Clark's Scale*, each degree of hardness is equal to 1 grain of carbonate of lime per imperial gallon. One grain of carbonate of magnesia is equal to about $1\frac{3}{4}$ grains of carbonate of lime. The sixth report of the "Rivers Pollution Commission 1868" give a scale in which a degree of hardness is parts per 100,000. By this scale the standard is 1 lb. of carbonate of lime in 100,000 lbs. of water = 1 degree hardness. Each

Hardness.

degree of hardness indicates the destruction and waste of 12 lbs. of the best hard soap by 100,000 pounds, 10,000 gallons of the water.

This *scale of hardness* can be converted into grains per imperial gallons by multiplying the number of parts by 7 and then removing the decimal point one place to the left. Thus, if there be 35.4° of hardness per 100,000 parts, the amount would be 24.78° according to Clark's scale.

Woodward in his "Geology of Water-Supply" notes that 8° hardness is considered best, but as much as 15° is not regarded as excessive, and 16° or 17° is permissible. The idea that chalky water is liable to produce goitre, or calculus is a fallacy. Enlarged spleens have been proved by Lt. Col. Norman Walker, D. M. & S., Nizam's Govt., to be casued by hyper-endemic malaria and not as the villagers thought from drinking certain *mineral* water.

Waters may be of either *temporary* or *permanent* hardness. Temporary hardness is due to presence of calcium and magnesium bicarbonates; permanent hardness, to calcium and magnesium sulphates. As indicated above, the test for hardness is the soap test. Messrs. Burroughs, and Wellcome supply Tabloids for this purpose which are most useful for field estimations. Table IX, shows the wide range of hardness in the underground waters in the crystalline rocks of the Dharwar and Peninsular complex. The Well Sinking Department have, as far as possible, endeavoured to supply drinking water below 25° of hardness; but, in specific instances, in the saline areas where villagers were going two to three miles to get their domestic supplies, higher degrees of hardness have been allowed and gratefully received.

Organic impurities.

Organic impurities may be derived from either animal or vegetable contamination. Vegetable contamination is caused by vegetable matter being allowed to fall into a well and rot. Though not dangerous in itself, unless present in large quantities, it forms a food for toxic bacteria and

should be kept down to a minimum. Organic impurities on the other hand caused by animal, or human pollution are always highly dangerous.

This pamphlet is no place for, nor is the writer competent to write on the subject of organic chemistry and bacteriology. It is sufficient to say that the presence of nitrates and nitrites, if found in any water and, especially if free ammonia is detected, should be taken as a warning and the water at once sent for bacteriological analysis.

In some books on sanitation the writer has found a rule laid down that, for the protection of wells, no building, nor any possibility of contamination must be allowed within an area, the diameter of which is calculated as 5 times the depth of a well. This is a wise precaution, but by no means ensures immunity. The distance that must separate a well from the nearest source of pollution is dependent on the nature of the pollution and whether the pollution has to filter through the soil to gain access to the drinking water supply or can gain direct access to the rock, as will happen with a cesspool, privy or manure stored in pits. It is also obvious that the geology of the locality forms an important factor in the question.

This subject has been admirably dealt with by various authors, with relation to the conditions in the countries they are dealing with, to whom I refer below.

In Hyderabad State, when private parties wish to obtain a reliable, safe house water-supply, free from contamination, irrespective of the rocks, on which the property is situated, the writer cannot advise anything better than a bore-hole fitted with a pump. Even then, the bore-hole should be carefully sited and the casing pipe carried to a sufficient distance into solid rock to cut off surface contamination. Even then, unless proper sanitary precautions are observed in the area, pollution may occur, as illustrated by Weidman and Schultz in Bulletin XXXV of the Wisconsin Geol: and Nat: Hist: given below. As stated, (see page 120,) if the country permits, nothing is more satisfactory than an

abyssinian, or driven tube well, but such sites are rare in Hyderabad State, save in the sandy beds of nullahs.

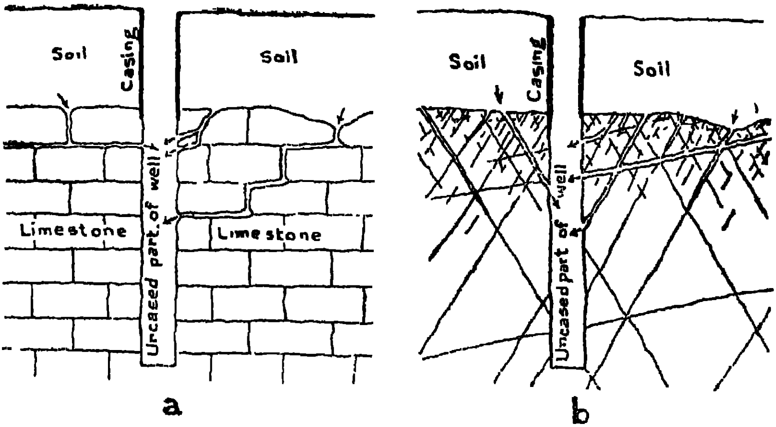


FIG. 14. Diagrams showing danger of pollution where casing is only carried as far as solid rock. Pollution from surface waters may sometimes gain access to bore-holes at great depth by means of fissures in hard rock (Fig a. after Weidman and Schultz, Fig. b. after Dixey).

The source and quantity of pollution requires consideration. In this country manure stored in pits undoubtedly forms the greatest danger. It must be remembered that the soil in village areas have for centuries been fouled by herding cattle, storing manure and the insanitary habits of the people. Any hope of obtaining pure water, except at a very considerable distance from the periphery of the village, is out of the question. Both Haviland and Fuller* have dealt with the contamination of well water by stored manure and it is obvious that in porous ground, contamination may extend to hundreds, even thousands, of feet

The writer's design of hexagonal and pentagonal mass concrete lining, hermetically jointing with the solid rock used by the Well Sinking Department, with a good apron platform, drain and parapet, (See Plate VIII), supplies a

* Haviland P. H. Domestic water supplies and sanitation on the Farm. Bull No. 622, Rhodesian Agrl: Dept. Fuller, M. L. Underground waters for Farm use. U. S. Geol. : Sur : W. S. P. 255.

water-tight lining, shutting off all shallow, surface, undesirable waters. If such wells are to be constructed by parties for private use, a cover is desirable and the well should be fitted with a pump, a trap-door being left below the pulley for raising water by hand.

It has been found, however, in the Canarese villages of the Raichur District, that, unless the villagers actually individually subscribe and pay for a pump or hand Persian wheel themselves, owing to their careless witless treatment will not last a month. The Well Sinking Department, have the greatest difficulty even to induce them to oil the pulleys on the wells.

The mineral waters of the State are very varied in contents. At Kinwat, north of Nirmal, a sulphur spring exists, while another hot spring is known to exist in the bed of the Godavery river at Badrachelam.

It is a wonder to the writer that some of these waters are not used extensively for medicinal purposes. A spring, issuing from the rock in the underground Shivaite temple at Umreshwar in Gurgunta Samasthan, Raichur District, is reputed to cure leprosy, but a careful analysis, including a test for radio-activity by Mr. McEwan, late Principal of the Nizam's College, proved it to have no special qualities.

The statement, Table XI showing complete analysis of water from different wells in several geological areas of the State, has been compiled through the kind assistance of the officers of the Nizam's Railway, the General Managers of Singareni Collieries and the Shahabad Cement Works.

TABLE

A statement of analyses showing the quality of water of some of the wells in the various Geological

No.	Location	Geological formation	Total suspended matter	Organic and volatile matter	Total Solids	Hardness Temporary	Permanent
1	Kazipet Ry. Stn. No. 1 Old Well ..	Archæan Gneisses	Very slight	0·06	48·5	27·5	11·9
2	Kazipet Ry. Stn. New Well ..	do	do	0·02	51·0	33	20
3	Dornakal Ry. Stn. Old Well ..	do	do	0·04	50·0	25·6	18·2
4	Dornakal Ry. Stn New Well ..	do	do	0·07	44·3	27·8	7·7
5	Mahbubabad Ry. Stn. ..	do	do	0·09	90·0	33·0	61·0
6	Chintalapally Ry. Stn. ..	do	do	0·06	32·1	21·2	7·3
7	Potakapalli Ry. Stn. ..	do	do	0·03	43·0	22·0	3·8
8	Nizamabad River Well ..	do	do	0·048	30·0	24·5	1·7
9	Ramgundam Ry Stn. ..	Lower Vindhyans	Traces	0·04	38·0	24·4	22·0
10	Singareni Collieries ..	Gondwanas	do	1·14	49·5	13·4	12·39
11	Tandur Collieries ..	do	0·25	..	182·1	31·0	35·20
12	Kohir Ry. Stn. ..	Deccan Trap	Very slight	0·04	60·0	28·0	10·5
13	Metalkunta Ry. Stn. ..	do	do	0·04	106·0	27·0	39·0
14	Manmad Ry. Stn. Well 2 .	do	do	0·027	32·7	24·1	1·9
15	Manmad Ry. Stn. Well 4 .	do	do	0·03	35·3	26·0	1 9
16	Manmad Ry. Stn. Well No. 5, near bridge.	do	do	0·027	36·7	25·6	2·6
17	Purna Ry. Stn. Glenfield Well ..	do	do	0·033	35·7	26·1	7·1
18	Purna Ry. Stn. River Well	do	do	0·09	50·0	25·5	2·6

XI.

formations of the State. The quantities expressed are in parts per 100,000.

Calcium		Magnesium			Sodium			
$CaCO_3$	$CaSO_4$	$MgCO_3$	$MgSO_4$	$MgCl_2$	Na_2SO_4	Na or KNO_3.	NaCl	Silica
20	6.3	9.0	..	5.4	..	..	..	7.0
8.5	9.0	22.0	..	6.3	..	..	..	5.3
17.1	5.4	15.4	..	8.1	..	..	..	3.5
15.7	4.87	13.4	..	7.5	..	..	..	2.5
25.7	11.0	15.7	..	31.0	..	..	..	5.2
15.7	Traces	9.0	..	3.4	..	..	..	4.85
11.7	1.5	17.4	..	3.5	..	..	..	7.1
13.0	2.1	8.1	..	..	.	..	4.7	2.0
18.7	0.85	13.7	..	2.1	..	..	..	1.71
13.4	0.19	..	14.63	..	3.53	..	15.81	..
28.26	..	2.3	42.03	..	15.52	..	81.0	..
20.0	8.0	17.3	..	7.5	..	..	..	2.0
12.0	27.3	19.4	..	14.5	..	..	26.0	4.3
11.0	2.7	9.3	..	..	..	..	6.1	2.5
12.1	2.7	9.8	..	..	..	..	7.0	3.0
12.3	3.4	10.0	..	..	..	..	7.3	3.1
12.3	4.2	9.8	..	..	..	..	6.1	3.0
13.7	3.4	8.3	..	..	5.7	6.0	6.1	5.7

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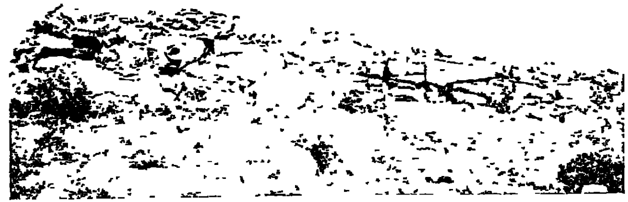
*NOTE. This lengthy list of references to works on and relating to the Geology of H. E. H. the Nizam's State, may appear out of place in this pamphlet. My excuse is, that no such list has ever up-to-date been published in any State Paper. I therefore, take this opportunity of making the information easily available. I have to acknowledge the Publications of the Government of India Geol: Survey Department, from which most of the information was drawn.

1. Dome gneiss, Bhongir Fort, Nalgonda Dist.



2 Mural Jointings in granitoid gneiss, Mudgal, Raichur Dist

3. Joints and tors in granitoid gneiss, Mudgal, Raichur Dist

4. Joints in Bhima limestones, Shahabad, Gulbarga Taluq.

PHOTO PLATE II.

HORIZONTAL FLOWS AND WEATHERING, DECCAN TRAP.

1. Trap layers, gorge, Ajunta

2. Section, ghat road, Tuljapur, Osmanabad District

3. Trap layers weathering into exfoliating boulders Well at Matur, Gulbarga Taluq

4 Decomposed Trap layer with columnar joints Purli, Parbhani District

ROCK WEATHERING

1 Porphyritic granite weathering into rounded boulders

2 Quartz veins in granitoid gneiss.

3. Chloritised schist, rhomboidal weathering Mile 24, Lingsugur-Tawargeri road.

4 Calcareous veins in decomposed acidic gneisses Fur 6, Lingsugur-Gurgunta road.

BARRIER ROCKS

1 Siliceous gray gneiss ribbed with quartz veins

2 Dolerite dyke, Pelipenta hill, Lingsugur

3. Dyke in a well section Basapur, Gurgunta Samasthan.

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PART IV.

Well Sinking

When a water supply is required, to decide whether it is best to sink a well or to put down a bore-hole, depends on the following factors:—

1. The depth from surface to permanent underground water-level.
2. The nature and hardness of the overlying strata.
3. The amount of water which is required per day.
4. Rate of yield, or porosity of rock from which supply is to be obtained.

Abyssinian or driven tube wells.

When merely household, or farm water-supply is needed and the spot is situated in the delta of a large river; or in an alluvial plain through which a river or stream meanders, and in which the alluvial is free from boulders, or in dry stream beds, or ancient or modern water courses, nothing is cheaper and better than a driven tube well.

There is much misapplication in the use of the name, tube well. A driven tube well was originally patented by Mr. Norton in England and was much used in the Abyssinian Campaign of 1868, from which it derived its name of Abyssinian well. It comprises a series of lengths of tubing, fitted at the upper end with a pump and at the lower end with a strainer, through which water is admitted, the strainer being protected by a mild steel driving point.

The first section, with strainer and driving point, is driven into the ground by a hollow cast-iron monkey, actuated by pulleys, and successive lengths of pipes are screwed on and driven into the ground, like the first, until water

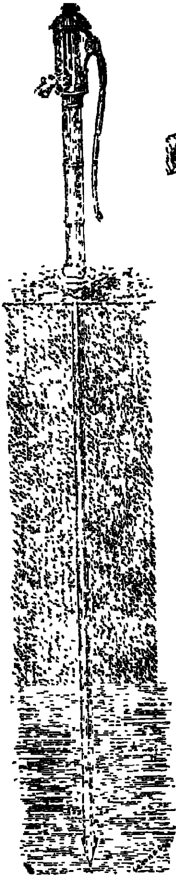


Fig. 1.

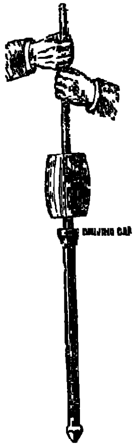


Fig. 2.

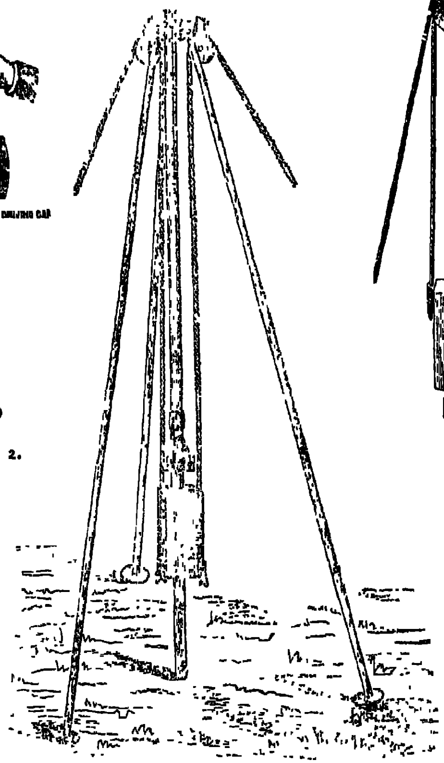


Fig. 4.

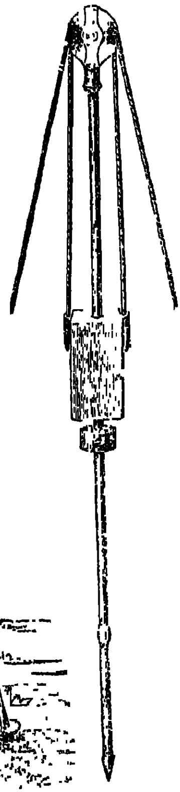


Fig. 3.

(The *Tube Well* consists of a perforated Well Point together with sufficient tube, in lengths of 5 feet, with one each of 3 and 4 feet to make up the necessary length—usually 30 feet. To the top of this tube a pump is attached as shown in Fig 1, but the type of Pump need not necessarily be that shown in this illustration

Fig. 2. This is the cheapest form and is only recommended for driving $1\frac{1}{4}''$ Tube Wells or the $1\frac{1}{2}''$ size if the ground is soft. It consists merely of a cast iron monkey which is raised by hand and guided to fall on the steel Driving Cap by the vertical bar fixed through it.

Fig 3, shows a more powerful apparatus in which the weight is raised by means of two ropes passing over pulleys. This Driving Apparatus can be used in driving tubes up to $2''$ or $2\frac{1}{2}''$ if the ground is not too hard

Fig. 4. shows a combined Driving and Withdrawing Apparatus which may be used for all sizes up to $3''$. The method of driving is shown in Fig. 4. For withdrawal of tube, the cast iron monkey is used for striking an upward blow against a clamp fixed to the tube below the coupling.

bearing strata is struck. Plate VIII, blocks for which were kindly supplied by Messrs Richardson & Cruddas, illustrates the plant.

The following essential conditions must exist to allow this patent to be used :—

1. Strata must be soft to allow the driving point to enter.

2. The underlying water bearing strata must be beds of sand or gravel with pores large enough to admit water freely into the tube through the strainer.

The rate of infiltration of the rock to be dealt with is a very important factor in the choice of type of well to be used. Where the rate of percolation is slow, the advantages of the increased surface of a dug well for increasing percolation is very big ; whereas, if the rock to be tackled has a high recuperative factor, a bored well would be as satisfactory as a dug well.

Boring.

The number of different types of drills on the market is very large. They all come under the following heads :—

Jet Process. In this process the casing pipes are sunk, by forcing water down a small pipe fitted with a jet inside the casing pipe, which removes the sand, the casing sinking by its own weight or helped by jacks. Such a method is only applicable in unconsolidated sands.

Hydraulic Rotary Process. In this method, the casing pipe is fitted with a cutting-shoe and made to rotate and the drillings are removed by water, forced down a service pipe and coming up outside the casing.

Rotary Core Drills. Such drills are sub-divided under shot and diamond drills. In the former, steel shot is let down the hole and acts as a cutter between the rotating drilling shoe and the rock. The resulting fine borings are removed by a powerful jet of water and the solid core, cut out by the peripheral cut, is drawn up to the surface within the tool. In diamond drilling the circum-

ference of the cutting bit is set, with bort diamonds, alternately on the inner and outer rims.

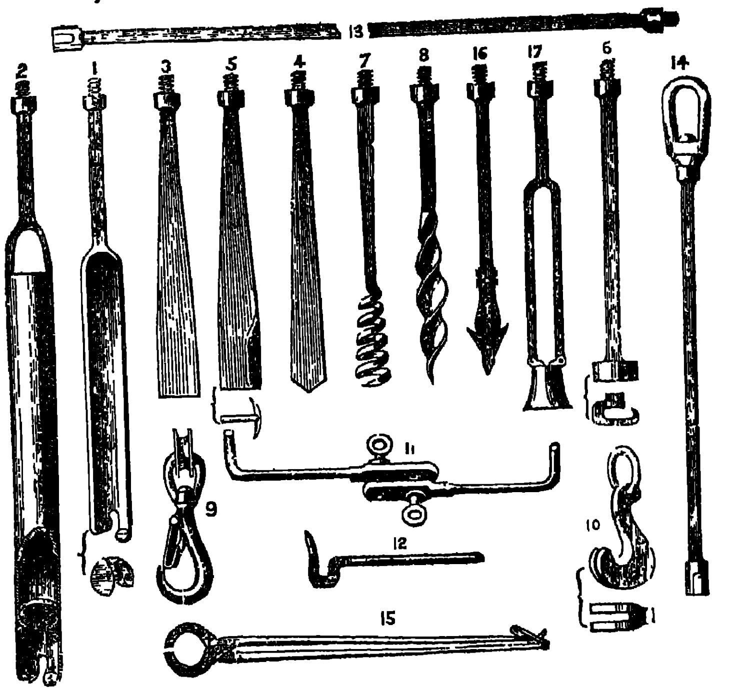


Fig. 15. Percussion Tools.

No.

1. Auger, for clay and stiff soils. 2. Auger—Nose Shell, valve for bringing up loose and saturated stuff from bore-hole. 3. Flat Chisel, for moderately hard ground. 4 V Chisel for moderately hard ground. 5. T Chisel, for hard and rocky strata. 6. Crow's Foot, for extracting broken rods. 7. Spiral Worm, for extracting broken rods. 8. Worm Auger, for loosening stuff in bore-hole 9. Spring Hook. 10. Lifting Dog, for raising rods 11. Tillers, for working the rods. 12. Hand Dog, or Rod Wrench. 13. Ten-feet length of rod, with screwed ends. 14. Short Rod, with swivel top. 15. Tongs, for making the screw joints of bore pipes. 16. Spring Dart, for drawing pipes up from bore-hole. 17. Bell Box, for extracting rods, in case of breakage.

Percussion Drilling- Such drilling is either done by hand for shallow bores, or by power for deeper holes. In either case the principal method consists of allowing cutting bits of various shapes to be alternately lifted and then dropped and thus the rock at the bottom of the hole is cut away. The cutting tools may be actuated either by rods or ropes, and are illustrated in Fig. 15 kindly lent by Messrs. Richardson and Cruddas.

Comparison of types of Drills.

Each type referred to above has its advantages for the special work for which it is designed. Rotary shot drilling gives good results in homogeneous, fine grained, extremely hard rocks, such as granites and quartzites. Should however the rock, although hard, be highly fissured, the shot and water is lost and, in such cases, percussion or diamond drilling is preferable. There is little doubt that the best plant for drilling would be a combined rotary shot and percussion drill, and this, in the hands of a skilled driller, should show good progress.

The cost of boring is a very difficult factor to arrive at as conditions prevailing in every hole are different. In the Well Sinking Department we have one Calyx G. O. Drill, and four composite Percussion Drills made up as follows :—

Details of percussion drill.

1 Winch and wire rope.
2 Flat blade chisels, 3½" and 4½", one of each.
2 V. blade chisels do do
1 Cross chisel.
1 Open clay auger.
2 Auger Nose Shells 3½" and 4½", one of each.
2 Shoe Nose Shells, 3½" and 4½" one of each.
5 Boring rods, 10' long, 5' long, 4' long, 3' long & 2' long.
1 Swivel rod.
2 Hand dogs.
1 Lifting dog.

1 Snatch pulley block.
1 Chain Wrench.
1 Derrick.
1 Lifting jack.

These percussion drills require the following labour :—

	O. S. Rs.
One maistry at Re. 1 per day	.. 30 p.m.
Four coolies at as. 6 per day	.. 11-4 ,,
Wages per mensem O. S. Rs.	41-4-0
Say B. G. Rs.	35-5-9

So long as moorum and decomposed rock is being drilled, the matter is simple and progress good; but, if a hard floating boulder, or hard gneiss is struck, progress per day is reduced to a few inches. The whole question is the tempering of the bits and supervision. The answer would naturally appear to be " Supply a trained blacksmith and increase supervision ." This is of course possible but at once the cost per foot is increased.

The writer finds that his Department is not unique in being faced with this difficulty of using cheap labour. In South Africa, after long trial, it has been found that for bored wells of any depth skilled labour (in that case European), with an efficient drilling plant, is in the long run cheaper than employing cheap native labour. But, in the case of the Well Sinking Department, at present working in a gneissic area, our bores are all trial holes generally to test whether the underground water is saline or not; and, as the water-table of the gneissic country we are now exploring averages about 30 feet, with practically the same wages required to run a drill, we can put down a trial pit. As explained below a bored well is not suitable for village supplies, owing to cost of equipment, upkeep and recurring monthly expenses. A bore-hole when complete is useless to us, whereas a trial pit costs little to enlarge to standard dimensions. Further in a trial pit, even if brackish water, which is good enough for cattle, is struck, the pit is of, value.

Further, boring to test for existence of drinkable water in the saline areas is apt to be very *misleading*. In many instances when drinkable water has been struck in bores, wells were sunk on the site, which gave undrinkable water, the cause being, that the larger diameter of the well opens out other saline springs not touched by the bore-hole. These facts have led the Well Sinking Department to sink trial pits in searching for village water supply in preference to bore-holes. All the above remarks apply to normal gneissic country, but when the surface is covered with a big depth of black cotton-soil overlying saline areas, trial bores are indispensable.

Bored Well.

In ordinary gneissic country, either for village drinking supply, or irrigation purposes, there is no question that a well is far cheaper and more serviceable than a bore-hole. On the other hand, if only household or small farm supply is needed, a bored well in the crystalline rock, carefully lined with casing pipe lowered sufficiently far into the hard rock, and drilled well away from all sources of contamination, will in all probability give a purer supply than an ordinary surface well. Such a bored well is limited to the capacity of the pump which is fitted to it. But for big supplies such as village drinking water, a properly designed well is much cheaper and more suitable for the purpose than a bored well, for the following reasons :—

(1) The chances of obtaining by bore-holes a sufficient supply of water in crystalline rocks, to supply a village, are highly problematical (see page 76 Fig. 12)

(2) Figures prove that the cost of boring and lining a bore-hole in crystalline rock equals the expense of sinking and lining a suitable sized well.

(3) In the case of a bored well, to obtain a village supply, the bore-hole would have to be at least 4″ in diameter at the bottom, and would then have to be fitted with a deep well pump, driven by an oil-engine, and a suitable sized storage cistern in case of breakdown. The cost of these extras alone will be greater than the cost of

the well, not to mention original cost of pump, upkeep, driver's wages and depreciation.

(4) On the other hand, a properly designed well allows villagers to draw their water by hand and the outlay is reduced to a minimum.

It has been argued that bored wells for village water-supply would overcome the objection of contamination by bacteria. But the writer cannot agree unless the bore-hole is drilled far outside the periphery of the village area. The average depth of the soil in gneissic country is shallow and saturated with chemicals and bacteria, derived from stacked and pitted manure, the accumulated filth of centuries and from the insanitary habits of the villager; so, instead of acting as a filtering medium, this shallow soil is but the storehouse of contamination which, annually, without any intervening filtering medium, percolates through cracks or fissures direct into the underground water-supply after each storm of rain. (See Fig. 14.)

Whether it has been decided to sink a circular or square well, the process in each case is for the most part similar. The advantages of a circular well over a square well are discussed elsewhere.

Excavation of wells.

After marking out the ground the work proceeds with pick, shovel, crowbar, and powrah (spade), the excavated material being removed by baskets. If the surface soil and sub-soil are very friable, the initial excavation of the well must be made larger so as to allow steps to be cut as indicated in Plate IX, page 138. As the depth increases the common local practice is to cut a sloping-roughly stepped incline, which is lengthened and deepened as depth increases. There are several advantages to this method in the work of the Well Sinking Department, as it finally allows the power-pump to be lowered down to nearly hard rock level. In general, after rock has been reached, the local contractors prefer to fit either a single or double pulley (mhote) fitted with a rope and bucket and the muck and water hauled out from the bottom of the

well by women coolie labour. Although the Well Sinking Department has demonstrated the advantages of a windlass, and double buckets, only the most go-ahead of the petty contractors employ them. When really solid rock is reached, a ledge must be left, by reducing the interior area of the well, on which to build up the concrete lining, or stone steining.

When solid rock is struck boring and blasting commences. The whole secret of success in sinking in rock, is the proper placing of the hole, in order that each charge shall do its maximum duty. Whether it is in a circular, or square well, the main thing is to get out the *centre cut*. This is done by drilling three or four holes, according to the dimension of the well, and the hardness of the rock, towards the centre of the well each marked 1 in Fig. 15a. A and B. The slope of the holes obviously depend on the depth to which the labour is capable of boring. These holes to form the centre cut are blasted first. The subsequent holes are so placed as to blow down the sides of the excavation towards the centre cut, as illustrated in Fig. 15 a. A & B. marked 2 & 3.

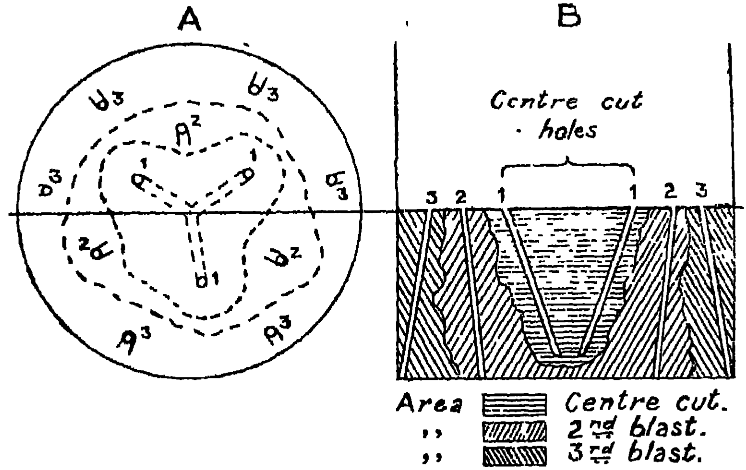


Fig. 15 a. shows the rough idea of the position and

number of holes required to blast out a 6 ft. circular well in hard rock,* the dotted lines in A show the proper effect that should result after blasting each set of holes.

To drill a good depth of hole by hand labour, say 3 to 4 ft., everything depends on proper sizing and tempering of the drill bits. In the Well Sinking Department, we advise the contractors to shape the bits of their drills to a template to the following sizes :—

When using 7/8 inch octagonal steel, the starting drill should have an $1\frac{3}{8}$ inch bit, next $1\frac{1}{4}$ inch, next 1 inch. When using dynamite, or gelignite no hole should be smaller than 1 inch diameter, as it is unsafe to force a charge primed with a detonator into too small a hole. If the bits are not correctly tempered they will loose their gauge so quickly that the resulting hole will sharply taper and the succeeding drill is sure to jam.

A certain amount of effective work can be done, in dry rock, using gunpowder, but of course it has but one quarter the strength of No. 1 Dynamite. When water-level is reached, gunpowder becomes useless, unless extraordinary precautions are utilized, which are nearly impracticable.

Guttmann, the great authority on blasting, sums up the question as to which is the best formula to use to calculate the correct quantity of explosive to charge into each hole in the following sentence. "There is no lack of theories for the determination of blasting charges, but their application depends on empirical facts determined by practical work. I therefore advise that the calculation of charges under ordinary conditions be neglected, and recommend watching actual operations for some weeks, asking explanation from the most expert miners. In this way experience will be gotten in a short time that will enable one to estimate with some precision the proper charge to use after inspecting the spot to be blasted."

In the centre cut holes, in the above diagram, Fig. 15 a, presuming they are 3 ft. deep, bored in hard homogeneous crystalline rock the writer would use $2\frac{1}{2}$ to 3, 2 oz. plugs of

* The holes should be blasted in the order indicated.

blasting gelignite, if in medium rock, $1\frac{1}{2}$ to 2 plugs, and in soft rock $\frac{3}{4}$ to 1 plug.

Step Wells.

Throughout the Gneissic area of His Exalted Highness the Nizam's State, with but very few exceptions, large open *baolis*, or step wells have been constructed by the villager or the Local Fund authorities, into which the villager, to fill his pots, has to enter the water by steps, either built, or cut in the sides of the well.

The danger of such wells from infection by cholera, guinea-worm, and other water-borne diseases, and, the insanitary practice of drinking water which folks' filthy feet have entered and in which everybody washes out their mouths, clothes, and bodies, the writer leaves alone, as being outside the purview of this pamphlet. The object, however, of the constructor in excavating wells of such huge dimensions, sometimes 150 to 300 ft. square, was undoubtedly to cut as many water-bearing fissures in the rock as possible.

Comparative cost of large square wells as against 12 ft. internal C. C. lined wells and tunnels.

If the question is examined on common-sense lines, it will be seen that the cost of excavating such a large quantity of material above water-level is a pure waste of money. For, instead of serving any useful purpose, it only adds enormously to the cost of lining the well, besides giving the final well a great area for solar evaporation and accumulation of wind borne dirt. If, on the other hand, a suitable sized well is sunk below permanent water-level and the money, spent in excavating the large amount of material in the open "baoli" above water-level is now utilized in tunnelling side galleries at right angles to the rock fissures, a well of the same depth and with an equal area of sump, or storage capacity can be excavated for half the cost. Further, as it is probable by this method that a greater number of water-bearing fissures will be cut, the small well with side tunnels will give the better recuperation.

The writer has to thank his staff, for calculating the following figures which prove his contention.

Comparative cost of sinking a 20 ft. square stone steined Deccani baoli, as against a hexagonal 7 ft. sided mass cement concrete lined well* having equal sump room, obtained by tunnelling, both wells 40 ft deep, and water level at 30 ft. from ground level.

Assumptions.

1. Strata same in both cases as below :—

Soft soil	7 ft.
Rocky mooram	9 ft.
Soft rock	9 ft.
Hard rock	15 ft.

2. In square well, dimensions 20′×20′, vertical retaining wall, on which mhote is fixed, built of C. R. S. masonry in lime mortar, the remaining three sides of well revetted with 4 : 1 slope of laminated stone 1½′ thick.

3. Below soft rock, sinking is vertical

4. In square well, sump is 10 ft. deep and 4,000 cft., holding 25,000 gallons.

5. Common items in each design of well, such as mhotes, ramp etc., excluded from calculation.

Estimated cost of square well 20′×20′, *depth* 40 *ft.*

Sinking.	O.S. Rs.		
64·07 units of soft soil at O.S. Rs. 2-14-8 per 100 cft.	186	13	11
70·53 units of rocky mooram at O.S.Rs. 11-10-8 per 100 cft. ..	822	13	7
36 units of soft rock at O.S. Rs. 17-8-0 per 100 cft.	630	0	0
60 units of hard rock at O.S. Rs. 35-0-0 per 100 cft.	2,100	0	0

* Note:—The standard 7ft. sided hexagonal agricultural well designed by the author, fitted with a specially designed mhote pulley and approved of by the Agricultural Department and the Famine Board is identical in method of construction to the well illustrated in Plate IX.

0·99 units of mooram filling behind C.R.S. masonry at O.S. Rs. 9-0-0 per 1,000 cft.	8	14	7

Steining.

32 units of C. R. S. masonry at O.S. Rs. 36-0-0 per 100 cft.	1,152	0	0
8·0 units of pointing at O.S. Rs. 4-0-0 per 100 sqft.	32	0	0
15·08 units of R. S. revetment $1\frac{1}{2}'$ thick at O.S. Rs. 9-8-0 per 100 cft. ..	143	4	2
Total cost of square well O.S. Rs. ..	5,075	14	3
or B.G. Rs. ..	4,350	12	3

Estimated cost of standard agricultural well, lined with 7 ft. sided cement concrete 9″ thick.

Sinking.	O.S.Rs.		
17·82 units of soft soil at O.S. Rs. 2-14-8 per 100 cft.	51	15	7
22·91 units of rocky mooram at O.S. Rs. 11-10-8 per 100 cft.	267	4	6
10·25 units of soft rock at O.S. Rs. 17-8-0 per 100 cft.	179	6	0
31·12 units of hard rock at O.S. Rs. 35 per 100 cft.	1,089	3	2
14·54 units of tunnelling in rock at O.S. Rs. 60-0-0 per 100 cft. (tunnels 6′×4′).	872	6	5

Lining with mass cement concrete.

643 cft. 9″ thick with 1 : 4 : 8 mixture at O.S. Rs. 65-8-0 per 100 cft. ..	427	11	5
1.61 units of filling and tamping behind C. C. lining at O.S. Rs. 12-0-0 per 1,000 cft.	19	5	1
Total cost of standard Agr. Well in identical strata giving equal recuperation and sump room roughly just half the cost ..	2,907	4	2
or B.G. Rs ..	2,491	15	0

After perusal of these figures, there is no doubt that this is the method that should be employed by landowners in sinking agricultural wells. The cost of making one 7 ft. sided hexagonal mould to cast a section 2 ft. deep and 9″ thick, is O.S. Rs. 312,=B.G. Rs. 267-6-11.

Failure of wells owing to springs getting blocked by precipitation of salts.

Before leaving the subject of these huge Deccani baolis, sunk for both village drinking water-supply and agricultural purposes, there is an important point which must be mentioned. Areas in the south-west and central parts of Hyderabad State are subject to successive years of diminished rainfall. The Raichur and Sorapur Districts are the most frequent sufferers in this respect, though other areas along the western frontier as far north of Bhir are also affected. The writer noticed that after roughly seven years of partial famine, many large old baolis failed to get replenished even after a decent monsoon and traced up the cause. It was discovered that, owing to the high percentage of calcium and magnesium salts in the underground water, that during the long years of successive droughts, when the springs in the well were barely seeping, owing to the high evaporation, all the salts were deposited and, finally, entirely closed the fissures. In many instances, when this was realized, by merely putting in long reaching drill holes into the closed fissures and blasting with a heavy charge, recuperation immediately re-started and the well filled up without any necessity of deepening. The writer now believes that in many instances, this was the cause of failure of many wells around Atraf-i-Balda (Hyderabad). These wells were replenished apparently with sub-artesian effect, when a bore-hole was drilled in the bottom. The agricultural engineer showed the writer several wells in granitoid gneiss, in which a bore-hole had given most successful results. The writer carefully examined the locality of the wells and could find no trace of dyke, or any cause, to account for water rising under pressure in the bore-hole put down in the bottom of the well. The writer is now

satisfied, that directly the bore-hole touched the first horizontal cleavage in the granitoid gneiss, it tapped the water, lying stanked back around the outer diameter of the well, into which it could not penetrate owing to the fissures being closed and thus caused the apparent sub-artesian effect. This reason for failure of wells should be looked for, before going to the expense of hiring boring tackle.

Failure of agricultural wells.

In the Raichur District the writer has noticed a large number of agricultural wells now disused. In the Annual Report of the Well Sinking Department for 1337–38 Fasli, (1928) this subject was discussed. There is little doubt that the main cause of well irrigation going out of favour in the Raichur District was partly due to failure of wells during one of the recurrent periods of drought to which this area is subject. During these periods the water table of the district sinks as much as 20 ft. in some places. The Indian cultivator can sink his well to rock, and through rock, using gun-powder, if there are no springs to stop him. Many of these agricultural wells must have been sunk generations ago below the then existing water-table, and from their number must have been very profitable. But, owing to cycles of insufficient rainfall, resulting with shrinkage of the water-table the owners frequently met with total failure of water, just at the most crucial moment and so lost their entire crop. Sinking the well deeper with gun-powder was impossible and so after repeated failures, during different cycles, well irrigation was abandoned for a dry crop The writer feels that if only sufficient inducement was offered, that by use of high explosives all these wells could be sunk sufficiently below the permanent water-table without any fear of failure of supply in bad years.

Shape of wells and methods of supporting walls.

The Well Sinking Department have finally decided that 4 ft. sided hexagonal and pentagonal shaped wells suit their purpose better than circular. But the reason for the arrival at this choice must not be over-

looked. The work before the Department entails sinking hundreds of wells, of two different sizes, one for ryots and smaller ones for the non-caste village populations. In our case where each set of moulds for casting a 4 ft. sided concrete cement lining is used over and over again, its original cost and depreciation, spread over a great number of wells, becomes an insignificant item added to the cost of one well. However, the original cost, *viz.*, O.S. Rs. 190 = B.G. Rs. 163, per set, to cast 2 feet deep sections, added to the cost of one single well is a matter of consideration. The reason for choosing hexagonal design is as follows :—

When circular moulds were used it necessitated having 2 sets of moulds, one for 10′ diameter linings, the other for 6 ft. diameter linings. A 4 ft. sided hexagonal lined well gives an internal area of 260 square feet, if one side of the mould is removed and joined up again to form a pentagon it forms the lining of a well with an internal area of 172 sq. ft. This saving in cost of having to keep in stock two shapes of circular moulds was one reason for the adoption of the design. The other was, that even though the circular moulds were made in three sections, they were not only heavy and bulky for carting, but, worse, they were continually getting bent and, in consequence, giving a great deal of trouble in joining together underground. Further, we had a lot of bother in bending the angle iron to the right curve, whereas with hexagonal moulds all these difficulties disappear.

Cost of mass Concrete cement lining.

The cost of lining a single well, by mass concrete cement 6″ thick works out as below :—

TABLE XII.

Comparative cost of lining a well with 4 ft. hexagonal mass cement concrete, or steining with coarse rubble stone masonry.

	Per foot in height.	
	C. C. Lining 6" thick	*C.R.S. Steining 1'-6" thick.*
Quantity ..	13 cft.	50·24 cft.
Cost O.S. Rs. ..	9 4 0	23 4 0
Supervision charges at 35·4 per cent. ..	3 4 0	8 4 0
Total O. S. Rs. ..	12 8 0	31 8 0
Total B.G. Rs. ..	10 11 5	27 0 0

It is, therefore, simply a question of how deep the well or number of wells that have to be lined to see whether it will pay a private party to construct a mould. But, whether the well is going to be lined with mass cement concrete or C. R. S. masonry, there is no doubt that circular or hexagonal designs outweigh square or rectangular shapes. One has but to tour the State and examine wells as much as the writer has done to realize the large amount of square or rectangular wells there are throughout the Dominions in a state of collapse, owing to incorrectness of design and insufficiency of batter to the revetment on the sides. The writer has only lately had an excellent example of the advantages of circular design. Within Jawalgiri Fort, (Sindhnur taluq) opposite the temple, is a 10 feet circular well, steined right to the bottom with loose dry steining. The well, which was 94 feet deep ran practically dry. By grouting the bottom 10 ft. of dry steining with cement, the Well Sinking Department were able to deepen the well, using dynamite, without any damage to the overhanging steining. After 5 ft. had been sunk a short tunnel struck a spring which filled the well within 61 ft. of the collar.

Care of choice of ground in which to cut ledge to carry steining.

A word of warning before closing this subject. In gneissic country when sinking wells, (whether to be lined by C. C. or steined with C. R. S. masonry is immaterial), a zone is frequently reached where the moorum

is hard enough to require an occasional pop with dynamite and has every appearance of being sufficiently sound to bear the weight of the lining or masonry steining. Take care! In our gneissic country there is a lot of decomposed rock, which is what is technically known as *hydrated*, and, as soon as the pressure is released, breaks up into crumbling fragments. The rock most commonly affected is a white rock with dullish green spots in it (binary acidic gneiss). It is as well, whenever it is practicable, to spend a few more rupees and invariably sink until a ledge can be formed, cut out of undecomposed rock. If the well is then sunk a further 5 ft. below this ledge deepening the well is possible at some future date without cracking the lining or stone steining. But, in our well sinking work, we come across many cases where decomposition, especially in the above type of gneiss, goes down to 50 and 60 feet without any solid rock being struck. In such cases there is no alternative but to start lining from the very bottom of the well.

Mutual interference of wells.

Mr. Lacey, in "Hydrology And Ground Water," page 104, gives the following table, showing the mutual interferenc of a number of wells sunk in a row. The wells are assumed to be 6″ in diameter, through the steining of which water passes as easily as through the soil, and the infiltration head is 10 ft.

TABLE XIII.

Distance apart of the wells in feet	Mutual interference per cent.	Distance apart of the wells in feet	Mutual interference per cent.
100	65·8	600	14·0
200	45·0	1,000	6·4
400	24·0	..	..

In the case of neighbouring wells in crystalline rocks or gneisses the above table will not necessarily apply. An examination of Figs. 11 and 12 shows it is quite impossible in these rocks to predict the possible interference. Owing to various water bearing fissures controlling the yield of some of these wells in undecomposed crystalline rocks, two wells within 30 ft. of each other have been found to give not only entirely different yield, but, in certain cases, entirely different quality of water, one being drinkable, the other not.

Wells in Deccan Trap area.

Save to say that, as far as the writer's inspection has gone, he sees no need to alter the design for wells already selected by the Well Sinking Department when work commences in this Deccan Trap formation, nothing more need be said for the present. The question of improving village wells by boring or by blasting through the intervening semi-impermeable layers of Trap overlying the water bearing underlying layer, depends entirely on the question, whether sub-artesian conditions exist in the porous layer below. This question can only be proved by a long series of trial bore-holes and far more intimate knowledge of local conditions must be obtained by this means before any opinion can be given. If water in certain decomposed layers of Deccan Trap are found to be under pressure the future of certain districts in Marathwara country will be entirey changed.

Wells in Laterite.

The writer so far has had no experience in dealing with wells sunk in laterite, but, from the chemical composition of that formation, he has a strong suspicion that some of the wells which used to yield ample supply but are now dry could be at once improved by driving short tunnels from the bottom, where the laterite lies on the unaltered lava flow.

Wells in loose ground or running sand and water.

When dealing with ordinary mooram overlaid with a shallow depth of black cotton-soil, in starting a well to be subsequently lined with a 4 ft. sided hexagon of 6″ mass cement concrete, the practice of the Well Sinking Department is to commence

sinking with a 14 ft. diameter. This diameter is continued until mooram is met, then reduced to 12 ft., by leaving a step 1 ft wide all round the periphery and sink at that diameter till sufficient solid ground is met on which to cast the lining. (See Plate IX). When using an inner and outer mould, the space left around the concrete after removal of the outer mould, must be most carefully tamped as lining proceeds and kept constantly watered, to ensure perfect consolidation. Normally, the platform should not be cast until at least two monsoons have passed, and the ground has been properly consolidated, but such a delay is impossible in the extensive work that the Department is undertaking.

Owing to the speed, with which we are able to line our wells, we have been able to excavate a well in black cotton-soil at Sindhnur Travellers' Bungalow, Raichur District, to the depth of 40 ft., without using any temporary support at all.

In using mass concrete cement lining there are many alternatives open to the engineer. The Water-Supply Section of the Nigerian Geological Survey* are successfully using concrete linings for wells up to 200 ft. in depth, put down in friable sandstones and clays of the Sokoto and Bornu Provinces. The internal diameter of the well is 4 feet, and the thickness of the concrete varies from 2½" to 6", according to the nature of the ground and the amount of side pressure expected. The concrete lining is put in with the aid of rolled iron shuttering, as sinking proceeds, and the following methods are employed, according to the varying ground conditions encountered :—

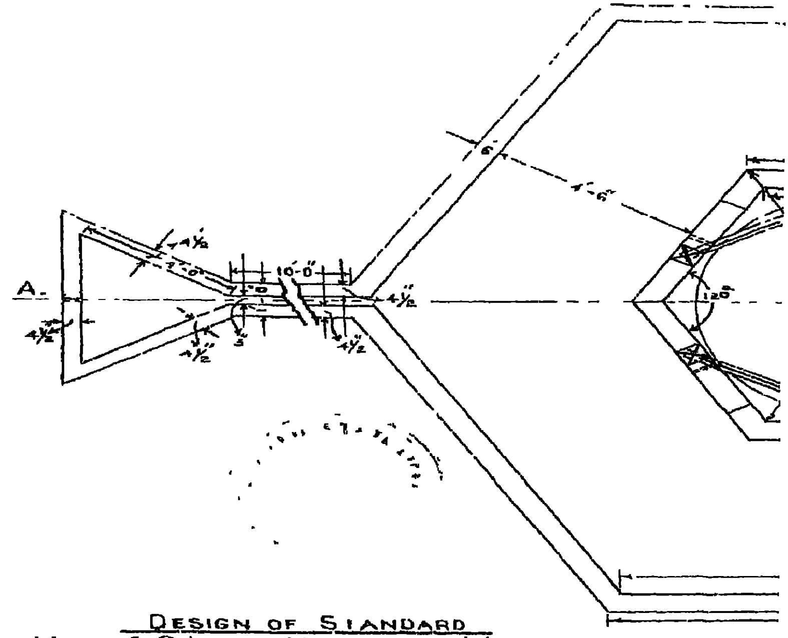
(*a*) Alternate sinking and lining with walling cribs (20-30 feet.)

(*b*) Alternate sinking and lining with short lifts (6-12 feet).

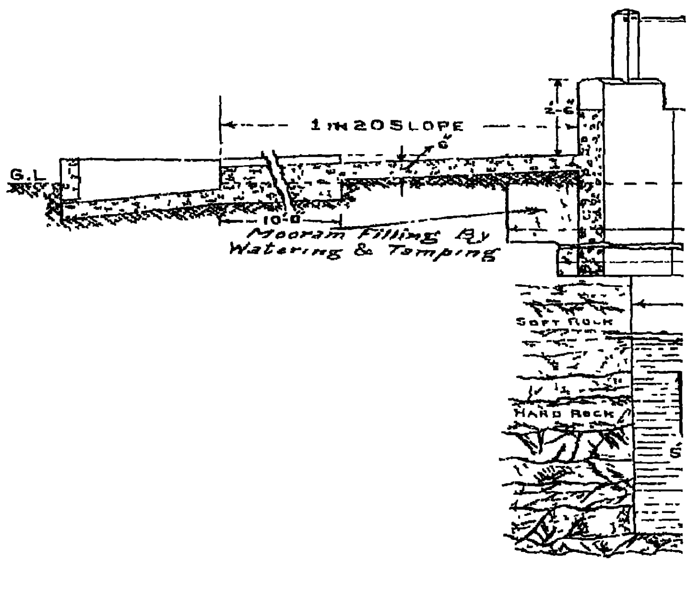
(*c*) Simultaneous lining and sinking.

Instead of having an outer mould, the well is cut to the exact size required, and concrete is filled in behind the iron

* Annual Report on the Geological Survey for the year 1931, Colony and Protectorate of Nigeria.



DESIGN OF STANDARD
MASS C C LINED HEXAGONAL WELLS.
HYDERABAD WELL-SINKING DEPT.



forms which must be most accurately centred. When pouring in the last concrete of a new section, a good joint must be made with the bottom of the upper section, and it is usually advisable to finish off the joint with cement. Where ground is friable and likely to lead to slipping of the concrete lining, better contact with the well sides is secured by cutting a continuous horizontal groove behind each section before the concrete is filled in. The first section of the well can be cast with a collar of concrete, resting on the ground, which will form the final platform to the well. The mixture of concrete used is the same as that used in the Well Sinking Department, *viz.* 1 : 4 : 8.

In very bad ground reinforced concrete could be used, though, so far, the Well Sinking Department have not come across the necessity.

Sinking wells as caissons, or on curbs.

In dealing with very loose sodden ground, which locally is called *soudu*, or when running sand and water is encountered, it is necessary to sink brick or masonry wells laid on curbs, or utilising cast concrete caissons. These wells will be sunk by means of undercutting. When brick or masonry is employed, it is necessary first to construct a curb on which the caisson is built. There is a lot of literature on this subject, and the writer need not detain the reader in this pamphlet mainly intended to deal with the geological side of water finding. Babul (Acacia arabica) is the most suitable timber to employ for curbs, as it is practically indestructible. The writer had a piece of babul taken out of the old gold workings at Hutti Gold Mine from a depth of 600 feet, which, though lying in water for perhaps 3,000 years, was still solid.

In using concrete no curb is required. The Well Sinking Department has been successful in sinking circular and hexagonal caissons without even a cutting edge, though these are preferable. The cutting edge can be cast simultaneously with the bottom section and if there is fear of boulders being encountered had preferably be reinforced. The two bottom sections should be made of 1 : 2 : 4 cement

concrete mixture and the upper of 1 : 3 : 4. At least a fortnight's curing should be given to the first two sections before the first undercutting is commenced, but the subsequent sections can be added as work progresses.

The ground where the caisson is to be sunk is excavated until the water-logged ground, or running sand is reached, when it is best to fill in with about 2 feet of carefully levelled sand on which to lay either the curb, or on which to cast the lower sections of the concrete caisson, including the cutting edge. Undercutting, as long as inflow is not too great, can be done by hand, and, in wells sunk for drinking purposes, dredges which are necessary for sinking caissons for bridges or other structures seldom are necessary. If the well on the curb or the mass concrete caisson is not of sufficient weight, extra weight must be added by means of sand bags. Lacey in "Hydrology And Ground Water," p. 112, para. 59, is very clear on this subject.

"The frictional resistance to the sinking of a well increases with the depth, so long as the amount of stuff dredged, or removed from the well, equals the amount of soil the well displaces; but it frequently happens that considerably more stuff is removed than the contents of the well, and the stuff, especially in the case of sand, runs or flows in under the curb causing the well, and the adjoining soil surrounding it, to sink together. If this flow of soil from any cause does not run equally all round into the well, the well may jam, or stick, in its course downwards, and commence to go out of position. It is therefore important, in the case of wells of large diameter, to be sunk to depths of 50 feet and deeper, that the weight of the steining should be such as to cause the well to sink by its own weight, before the amount of material dredged exceeds the column of soil displaced by the well. A well should keep continually sinking, so as to cut off the outside material entering it, and thus reduce the amount of stuff to be excavated. A light well would only drop at intervals, and far more stuff would be dredged out than the volume content of the well sunk; a heavy well, on the other hand, would keep continually sinking, and thereby cut off the outside material flowing in.

"Sir Robert Gales, M. Inst. C. E., has introduced a term called 'sinking effort' per square foot of the outside skin of the steining. That is, the total effective weight of the well steining plus any extra loading on the well divided by the area of the skin or outside surface of the steining below ground level As deep wells for a water supply

are generally sunk through saturated soil, the effective weight of the steining is its weight in water.

"For all practical purposes, in the case of wells sunk through 'recent' alluvium, the sinking effort in *cwts.* per square foot of the skin of the steining is one-thirtieth of the depth below ground surface the well has to be sunk. That is, if borings disclose that in order to obtain a copious supply of water it will be necessary to sink a well to a depth of 120 feet, the sinking effort per square foot will be 4 cwts., from which figure the necessary amount of thickness to be given to the well steining can be deduced. It is obvious that if the steining is of sufficient weight for the well to be sinking as excavation proceeds, the expense and the delay in placing and removing the surcharged weights, when a new course of masonry has to be added, are obviated."

The writer has found that, should caissons get hung up, a very useful tip is to stop pumping, let the water rise and explode a quarter of a plug of gelignite dropped into the centre of the well. Such a small explosion generally has an instantaneous effect but, in some cases, it has taken a couple of pops to make the caisson properly settle.

Water in sand

Few of the minor rivers and streams of Hyderabad State are perennial, but, when the flow has ceased, long reaches of sand remain exposed, to all superficial appearance, bone dry. But this is not so, for, even a shallow pit, dug in the sand, will at once fill with water. Now, when it is remembered that every cubic foot of saturated sand contains rather more than 2 gallons of water, it is obvious what enormous reserves are at our disposal.

Save when a town water-supply is contemplated, very little research into this vast storage has been made in the State, though Sir Alfred Chatterton took a great interest in this question, and his book, "Lift Irrigation"* contains a lot of useful data. Sir Alfred frequently notes that the

* Chatterton's 'Lift Irrigation' contains interesting data as regards wind mills, a means of raising water now extensively used in S. Africa, Australia, aud America. Now that British machines are so much improved, as to be nearly fool-proof, and should be far more extensively used than they are in the Deccan. Investigation in this matter is called for first of all by the Meteorological Departments to find out which are suitable areas for their use.

poverty of the villager prevents him from making full use of this wonderful reservoir. But there is one indigenous method in use called in English a *Spring Channel* which, as it utilizes and illustrates the frictional resistance of water in sand, is worth describing. The spring channel, is a ditch which is arranged so as to run up-stream the bottom of which is cut to a slope less than the surface gradient of the river sand bed. At first this channel, or shallow trench, runs through dry sand, but, as it progresses, it cuts, then runs below the water level of the water-table beneath the sand, and from that point, onwards in its up-stream course, becomes an infiltration trench. The water, thus collected, runs down the channel into the trench dug in the dry sand and so flows into the pit, or "*chelma*," dug in the bank from which it is baled on to the fields. The first inflow into the trench, in the dry sand, is all absorbed until an area, beneath and on either side, is fully saturated up to the level of the hydraulic gradient, when the water from that time onwards flows on with but very little loss. The laws, illustrated by this simple process of obtaining water stored in sand, pertains, more or less to all other processes. In a spring channel the lower sandy section, in which, as described above, water after saturation of the sand is able to flow over it without any great loss, is cut in fine sand. If this sand were very coarse, the friction would be so much less that the water would filter away, at such a rate, that only a very small percentage would reach the chelma or collecting pit. The filtration of water in sand is in direct ratio to the size of the grains, and has been dealt with under the section on Permeability page 18 *et. seq*. Below is given the figures taken from U.S.A. Geol. Sur. Water-Supply Paper No. 219, page 27 :—

TABLE XIV.

Type of sand	Diam. in inches.	Velocity with gradient of 100 feet per mile — Foot per annum	Foot per day
Fine sand ..	·006 or 1/160 nearly	304	1 ft. per day nearly
Medium sand.	·014 or 1/70 ..	1,650	5 ft. do
Coarse sand .	·06 or 1/33 ..	7,577	22 ft. do
Fine gravel ..	·12 or 1/8 ..	121,296	33 ft. do

The above may be taken as a rough section of the grades of sand in the bed of an ordinary nullah, but, owing to total friction unless an artificial hydraulic gradient is formed, such as a deep trench or a well, the total water in these layers of sand may be taken as practically stagnant.

Owing to the friction controlling the inflow of water into a well, it will be seen that the deeper the well is sunk into the progressive coarser layers, the greater will be the inflow into the well. Besides, each successive layer has, by its grade, a separate hydraulic gradient becoming flatter and flatter until the gravel is reached, when the hydraulic gradient is practically horizontal. So every endeavour should be made to sink a well to the lowest limit of the nullah sand.

Grading bottom of well sunk in sand.

The writer has not yet had a very large experience of sinking wells in sand. He, therefore, welcomes the small pamphlet, written by Mr. F. C. Temple, "Surface Wells in Sandy Strata" (Thacker Spink 1918). In this the author specially deals with the silting up of wells through the influx of fine sand, drawn into the bottom of the well with the water, when heavy pumping is instituted, so

finally reducing the total percolation. The author advises, and it is obviously correct, that in open wells this difficulty can be overcome by putting a graded sand bottom into the well to produce such a condition of stability in the sand, that the rate of inflow into the well, through pumping, may be increased far above the *critical velocity* of the sand. The author defines critical velocity as that speed at which water may pass through sand without moving or lifting it. Mr. Farrant, sometime Chief Enigneer, P.W.D. Punjab, fixes the critical infiltration head for Punjab sands at from 5 to 7 ft. At the Trichinopoly Water-Works, South India, the fine sand of the Cauvery river is drawn into the pumps when the pumping head exceeds 5 feet. Mr. Lacey states, that in the case of coarse and heavy quartz sands, the critical head is over 7 feet.

Mr. Temple's idea which seems absolutely sound is designed to overcome this difficulty.

The principle employed is the reverse of the slow sand filter bed, used for purifying water, in which fine graded sand is laid on coarse sand over gravel, with a bottom layer of broken brick or stone. While sinking the well, samples from each foot of the excavated sand are taken and bulked together, mixed and a sample taken of the bulk and tested in a nest of sieves. A useful set of sieves for this purpose is comprised of 8 sieves with 10, 20, 30, 40, 60, 80, 100 and 125 holes to the linear inch.

Now presume a well is sunk in sand which gave the following grading :—

Rejected by	10 meshes	to the linear	inch per cent.	0·5
	20	do	do	0·5
	30	do	do	0·4
	40	do	do	0·6
	60	do	do	14·0
	80	do	do	28·5
	100	do	do	11·5
	125	do	do	29·0
Passing	125	do	do	15·0

This last grade is a very fine sand and will never yield water very freely, because the passages between its grains are so very small. The critical velocity will be low. The sand itself contains a very small proportion of large grains and it will clearly be necessary to keep the bulk of the fine stuff stationary. It is, probably, only possible, while the bottom is unprotected, to lower the water about 18 inches before the sand begins to move.

The 15 per cent, which passes 1/125 may therefore be ignored. All that is within reach of the in-draught of the well may come away without doing any harm. In fact, it will prove an advantage by clearing the passages of approach. The first layer of grading must stop the 1/125 sand. The correct size for this is 1/31. For this purpose sand, passing 1/30 mesh sieve and rejected by 1/40 mesh, may be used. It must be clearly understood that, before grading at the bottom of the well is laid, the water in the well must have been allowed to rise to high water-level and all recuperation stopped. At the depth, at which it is to be placed, there may be some difficulty in laying it evenly. It is enough if a thickness of 1 foot is provided. With so thick a layer it is certain that no part will be too thin. This should be thrown as evenly as possible over the whole bottom of the well. A paddle should be attached to a long bamboo and the surface of the 1/30 mesh sand should be smoothed with it as well as may be. The next layer necessary is stuff passing 1/8 mesh and rejected by 1/10 mesh. One foot of this should be spread out in the same way. Over this should be a one foot layer of stone broken to 1/2" size and over this, again, one foot of 2" ballast. This has reduced the depth of the well by 4 feet; but, in consequence, the water level can be lowered, probably almost down to the ballast, without the inrush of water causing any movement of the sand or ballast. Should any disturbance be noted, a layer of half bricks will stop it.

The section of the bottom of the well will now be as below :—

1′ of 2″	
1′ of ½″	
1′ of 1/8″	4 ft.
1′ of 1/30″	

Now let us take the case of a coarser sand and suppose the grading to be as follows :—

Rejected by	10	meshes to the linear	inch per cent.	18·0
Do	20	do	do	26·0
Do	30	do	do	18·5
Rejected by	40	meshes to the linear	inch per cent	16·0
Do	50	do	do	8·0
Do	60	do	do	9·0
Do	70	do	do	0·5
Do	80	do	do	2·0
Do	100	do	do	1·0
Passing	100	do	do	1·0

The analysis shows this to be a sample of a coarse sand. It is clear from observation that the 44·5 per cent. of 1/20 and 1/30 sand will, together, take care of all the remainder except the 1/100. There will be no harm if that comes away. As before, it will prove an advantage by clearing the passages of approach. In this case it will be sufficient to begin with a layer of 1/8″ sand and follow that up as before.

The section therefore at the bottom of the well will be as below :—

1′ of 2″	
1′ of ½″	3 ft.
1′ of 1/8″	

The same principle can be followed in an infiltration gallery. A trench can be dug and a concrete floor laid on the bottom. On this an earthenware pipe can be laid with open joints. The pipe is packed with gravel of the size of a plum or lichi, outside that with gravel the size of a pea, and outside that again a filling of coarse sand. If the sand of the nullah itself is fine, a medium layer of sand must be placed, overlying the coarse sand. The packing, can be done with sheets of iron or other suitable material, placed vertically at intervals around the earthenware pipe, to keep the different layers apart until the packing is finished.

Testing the yield of wells.

When a well is being sunk it is essential to remember that it must be carried down sufficiently far below the existing water-table. This is necessary for two reasons. First, in districts liable to insecure rainfall, the fluctuation of the water-table will be large. Elsewhere it has been shown that in the Raichur District the water-table has lowered in places through successive years of drought as much as 20 ft It is to gain this proper depth that the Well Sinking Department have been compelled to use power pumps as hand baling is insufficient now that the water-table of the Raichur District is being replenished by better monsoons after a long period of drought. This lack of sufficient depth below a fluctuating water-table was the cause of failure of most village drinking water wells in 1337 F. (1928), after seven years of droughts, and presumably the major cause of the abandonment of well irrigation in the Raichur District in the past. It would be as well for the Agricultural Department to check this point in other districts in the State. Secondly, it is necessary owing to the fact that directly pumping or drawing from a well commences the water-table radially around the well becomes locally depressed. This depression which is in the form of an inverted cone, see Fig. 16., is termed the *cone of exhaustion* some authors call it the *cone of depletion:* The area and the curve of the slopes of this cone will vary according to the porosity of the material from which the water is

being withdrawn. In ordinary cases the cone may extend from about 100 to 500 yards radially around a well, if heavy pumping is being carried on, and at times up to half a mile in width in the case of wells sunk in sand.

The capacity and yield of relatively shallow wells depends on many factors, but mostly upon the degree of fineness of the material in which the well is sunk. This fact must be the guiding factor when deciding what size a well should be sunk. In a fine-grained and only slightly fractured rock that yields water very slowly a dug well of say 10 ft. diameter would give far and away more satisfactory supply than a bore-hole. This is because the dug well gives far larger infiltration surface and a greater storage capacity.

The yield of a well sunk in a rock with a good specific yield also depends upon the depth it has been sunk below the water-table, for this will control the depth of the cone of exhaustion that can be made.

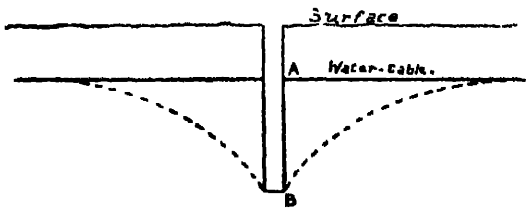


Fig. 16.

In the above figure the cone of exhaustion is shown in dotted lines and A. B. the depth of the inverted cone. When pumping is going on, A. B. becomes the head under which the water flows into the well. Theoretical considerations seem to show that the yield of a well is directly proportional to a certain transmission constant or specific yield of the porous rock in which the well is sunk, and nearly proportional to the head A. B. or depth to which the local water-table is lowered. This being so, if a well is deep and relatively small, say 6 to 12 inches in diameter, increasing the diameter seems to have little effect upon the recuperation,

for even doubling the diameter adds barely 8 to 10 per cent. to the theoretical yield. If on the other hand the well is relatively shallow and proportionately large in diameter the yield seems to be proportionate to the diameter, so that doubling the diameter would double the flow. This dependence of yield upon diameter is only true when the well is being used up to nearly its full capacity.*

As stated above, the flow of groundwater into a well sunk sufficiently deep below the water-table varies directly as the depth to which the water is lowered below the water-table. This is fully borne out in the graph below. It must be remembered that while sinking is in progress the well area has been daily drained, but in testing the capacity of an old disused well it is necessary to give the well at least 24 hours continuous pumping before a test is made.

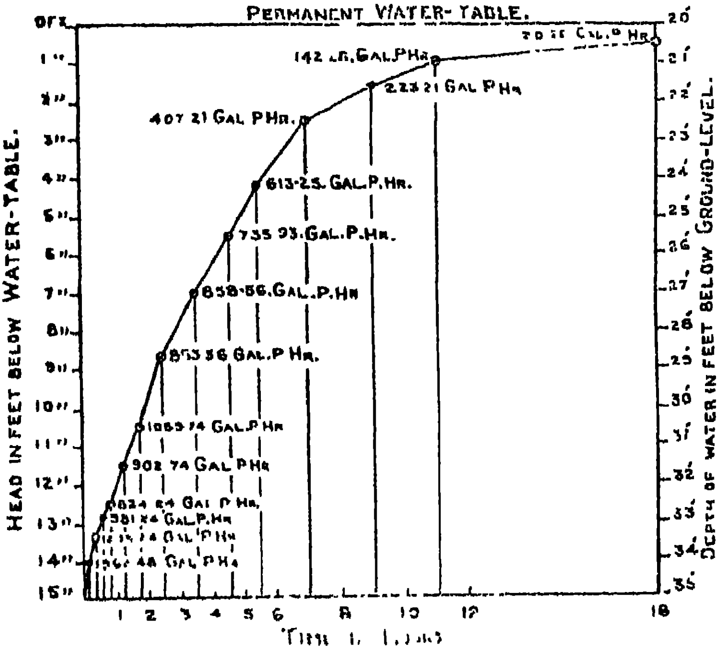


Fig. 17.

* After Dixey, Meinzer and Schilchter.

The well in question, whose test supplied the above graph is sunk in the area of decomposed acidic binary rocks at Kurkundi Travellers' Bungalow, Manvi Taluq. Reference has already been made to this area on pages 73 and 74 and the geological conditions illustrated in Fig. 11. The section of the well is : Soil 5 ft. Decomposed gneiss 30 ft.

As it is a standing rule in the Well Sinking Department that lining must be started from a ledge of solid rock beneath which there must be a sump of 5 ft. to allow for further sinking without hurting the concrete lining, it was necessary in this case to be assured that the well gave more than ample recuperation before allowing lining to be started from the bottom of the well. As stated elsewhere wells sunk in this class of decomposed rock may have to go down as deep as 60 ft. before any solid rock is struck.

In this case as the requirements were relatively small, to save excessive cost in concrete lining the rule had to be broken and lining started from the bottom of the well without a ledge and sump being left.

Wells in the Crystalline complex which obtain their water-supply from fissures cannot be said to form cones of exhaustion radially around the well as illustrated in Fig. 16. In such cases the fissures, which themselves are interconnected with a ramification of other fissures will probably form several cones of exhaustion perhaps at considerable distances from the centre of the well. An examination of Figs. 12,19 and 20, will explain this point. Such wells may be termed *spring wells*. Besides, the theoretical considerations referred to above will not hold good for those have been calculated from homogeneous unfissured material. In the well in question, however, the theoretical considerations and the illustration of the cone of exhaustion will apply as the material in which the well is sunk has more or less the consistency of coarse sand and the yield comes from seepage over the whole excavated surface of the walls of the well. Such a well may be termed a *percolation well*.

The graph has been plotted without adjusting the calculations. The apparent discrepancies at the end of the first and second hours, where the calculated recuperation comes respectively below and above the average is due to the unavoidable divergence in average diameter of the well. The graph clearly shows how necessary it is to take at least a 12 hours test else, most wrong conclusion will be drawn as to the capacity of the well. This is even more clearly exemplified in the graphs taken from spring wells. It may take a well days, sometimes weeks to regain its normal level. This test was made before the monsoons had started to replenish the water-table, so the cone around the well was at its lowest capacity of recuperation.

The graph clearly illustrates the theoretical calculation that the yield is nearly proportional to the head A. B. or, in other words, the depth to which the cone of exhaustion is lowered. There is no doubt that if this well were to be sunk deeper a far larger yield could be obtained. This is the class of decomposed rock which exists around Vedvatti east of Raichur referred to on page 73 and from which the writer hoped to obtain sufficient drinking water for the needs of Raichur town, which might save Government many lacs of rupees.

A recuperation test for a well as illustrated above requires no apparatus save a tape. It has been found that it is a more practical method than testing wells by pumping the water through a notched gauge. Unless close and very accurate readings of the gauge are taken, serious errors arise. With the recuperation test, knowing the average diameter of the well and the hourly rise of the water over 12 hours, little error is possible.

Village water-supply.

At the commencement of the work of the Well Sinking Department a good deal of discussion took place as to what were the actual requirements of villagers per head of population. In 1337 F. (1928) it would have been impossible to follow the rule laid down in most text-books of giving 10 gallons per head of total population for the simple

reason that after 10 years of insufficient monsoons in the Raichur District, such an amount of water was not available.

Enquiry from the villagers led to no practical result, as they so overstated their needs that it was obvious, that they were grossly exaggerating, for, if they used the number of pots of water they stated per head, per day, the wells would have been dry long before mid-day. We finally came to the conclusion that, when villagers have to draw water from a well by a rope, they use, on an average of 7 gallons per head of adult population, and this quantity covers the needs of the children. This is taken as the minimum allowance and has been found to tally with their needs. The non-caste population use considerably less. It must be remembered that the village supply is not drawn upon continuously throughout the 24 hours. Drawing starts shortly after sunrise, is at its maximum between 7 and 9 a.m. After 10 a.m. there is a lull till about 4 p. m. when water is drawn, off and on, till sunset. It is owing to this sporadic drawing and the time the well is allowed for recuperation during 6 hours of daylight the 12 hours of darkness, that wells, with a moderately small recuperation, can give the necessary minimum supply. The Well Sinking Department allow one well per 500 head of adult population, and each well is given one pulley for every 100 head of population.

There is no doubt, that terribly insanitary as step-wells are, they allow the villager to draw his daily needs faster than when forced to draw by pulley and rope. This of course is one of the main reasons why the villager has such a strong objection to having their village step-wells blocked and reconstructed into a draw well for the purpose of eradicating guinea-worm which is wide spread over the west and south-western districts of the State. The method of reconstruction and eradication of the guinea-worm is effected by first pumping the well dry and adding sufficient unslaked lime to raise the temperature of the remaining water to boiling point. The sides of the well is then washed down with this strong alkaline solution. By this method

it is certain that both guinea-worm larvae and cyclops (water-flea) are killed, and it is also believed that the eggs of cyclops are destroyed, which will not necessarily happen if the well water is merely made alkaline to kill the parent. For full discussions on this subject of guinea-worm eradication see Annual Reports of the Well Sinking Department.

Directly a pump or a hand Persian wheel is added to a well the amount of water used and wasted increases tremendously, owing to each villager taking a bath under the pipe and due to the waste of water from excessive pumping when filling pots. It was hoped to overcome this difficulty by making the pump or Persian wheel deliver into a small cistern. However, the villagers of different castes, although, quite willing to fill their pots from the same well in which all have paddled, spat, and perhaps bathed, refuse to fill their pots from the same cistern! It is impossible to battle against such distorted mentality.

It is not every well that has sufficient recuperation to stand the waste resulting from the fitting of a pump. Besides owing to the negligence and destructive traits of the villagers, in those cases where Persian wheels have been fixed, as an experiment, they have been broken in 3 weeks. It is found that it is only when the villager is induced to subscribe to the pump or Persian wheel, that the machine is taken care of.

Emergency wells.

District Officers, at times, are faced with the necessity of obtaining some sort of drinking water supply, perhaps in the case of famine or in the case of a tank breaching and the only available drinking water having run to waste.

In such cases speed is an important item. Wherever the water is located, either in the sand of a nullah or in loose mooram, an excellent temporary lining to support the sides of an emergency well can be made from corrugated iron, bound at the top and bottom with bands of flat iron like a municipal dust-bin. Such linings can be used as caissons, if suitably, weighted, and, if first painted

with rust proof paint, will last 10 years. The writer has in exploration work used bamboo or wattle basket-woven cylinders as a temporary measure, with great success.

Increasing the yield and capacity of wells.

The necessity of increasing the capacity of a well frequently becomes of the greatest importance to the manufacturer or agriculturist, and is a problem that comes practically daily before the Well Sinking Department, in the course of their ordinary duties. The Well Sinking Department are constantly being shewn wells which villagers claim had ample water-supply ten or twenty years ago. Here, in such instances, two questions at once arise, (1) has the water-level of the locality shrunk owing to long years of insufficient rainfall? or (2) have the fractures or crevices, which allowed the springs to flow into the well, become blocked, as has been described above on page 132? If the latter is the case, the remedy is easy. If the former is the case, sinking the well down below the water-level is the first essential.

Now suppose, after this has been done, that recuperation does not come up to the needs of the population and the question arises whether to sink further or whether to put in lateral drives or galleries, let us consider what factors should guide our decision.

It is at once obvious that each individual well has its own peculiarities, that each class of rock has its own characteristics and that a hundred and one factors come into play which it is impossible to deal with here individually. The writer believes that, if the following suggestions are carried out, using common-sense, and the reader fully understands they are not written as hard and fast rules, these ideas will be found to be helpful in getting increased recuperation :—

(1) In gneissic or granite country, if the well is still in decomposed rock, sinking should anyhow be continued till solid rock is struck.

(2) When solid rock is struck, which is apparently without fissures or cracks, a type of gneiss which the Public

Works Department define as *sheet rock*, and the class of rock from which *stone waddars*† burn off slabs, to continue sinking would be waste of money. In such a case, the only hope of increasing the recuperation is to tunnel along the junction of the mooram and rock, and so open up a larger surface for percolation. There is another point of importance to be considered here.

If the well in question is sunk on the flank of an outcropping boss of granitoid rock, the rainfall off the hill will sink beneath the talus and mooram at its base, and, the underlying rock being impervious, the water will flow down on its surface into the main water-table in the plain beyond. Lateral tunnels or percolation trenches cut parallel to the periphery of the hill and at right angles to the underground flow, will increase the recuperation. See Fig. 18, below.

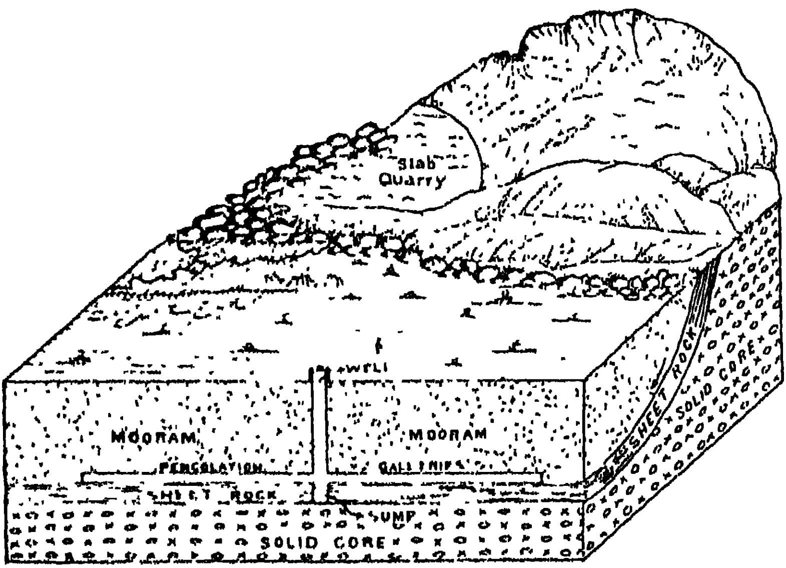


Fig. 18.

† In India there are wandering tribes generally called stone, or earth-waddars, whose hereditary professions account for the affix to their tribal name.

(3) The following may be taken as a rough and ready rule and must, like all such rules of thumb, be used with common-sense. Nearly all rocks have two planes of cleavages, very frequently more or less at right angles to each other. One of these cleavages may be classified as the main cleavage. Irrespective of what rock formation is being dealt with, if the bottom of the well which needs greater recuperation shows fractures, cleavages or bedding planes, either vertical or dipping at a high angle, the best chance of increasing the water-supply is to tunnel into that side of the well into which the fissures, etc. dip, a second tunnel being driven at right angles to strike the cross cleavage. If, on the other hand, the fissures, cleavages etc. are lying nearly horizontal or at an angle less than 45° with the horizon, it is better to sink. The underlying principle is explained in the Figures 19 and 20 below :—

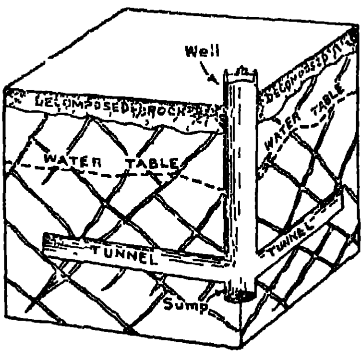


Fig. 19, shows that by tunnelling in rock, with fissures lying at a high angle, new water bearing fissures are struck quicker by tunnelling than by sinking.

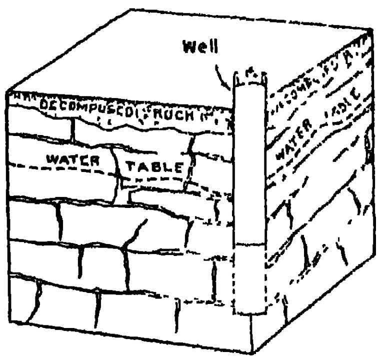


Fig. 20, with the water bearing cleavages lying at a low angle, it is preferable to sink.

The question of improving the capacity of wells in Deccan Trap has been dealt with on page 137 and, although an improved supply may be obtained at each parting

between the successive layers of hard Trap, the only hope of getting a really good and dependable supply is to sink to the next decomposed porous layer. The question, as to which of these porous layers hold water under pressure, is not yet known. When such a layer exists, boring from the bottom of the well is ideal ; but, if the pressure head of water is but weak, the well itself would also have to be deepened to make it form a reservoir, in which the water from the bore may collect.

In cases of wells sunk in laterite, tunnels at the junction of the laterite and unaltered rock are advocated.

Bored wells.

According to the average illiterate driller, the panacea of all evils is to dynamite the hole and believe that increased recuperation will always result. This is not the case, and is the result of loose reading and mixing up ill-digested facts, some probably referring to oil wells.

Improvement after blasting may be obtained in the case of holes bored in hard formations, such as quartzite and crystalline rocks, but it gives no results whatever in softer formations. A series of small blasts are preferable to a single heavy charge and, besides, the chance of damaging the casing pipe is reduced.

Generally speaking, in bore-holes to which pumps have been fitted, it will be found that the falling-off of the yield is most likely due to the clogging of the screen protecting the foot-valve, or some such cause, rather than diminution of the recuperation

Infiltration galleries, (karez) and sub-surface dams.

In spite of the fact that the rainfall of His Exalted Highness's State is not only not high but confined practically to the monsoon period, the writer is satisfied that not sufficient advantage is taken of the available water lying in the talus at the base of hills and plateaux especially in the Deccan Trap area. The best example of the underlying principle is the water works of Aurangabad, probably laid out by Persian Engineers in the days of Malik Amber, in the early part of the 17th

century. The best description of the Karez is to be found in a book " Sub-surface water of Iraq, " by A. H. Noble, but this principle of recovery of sub-surface water is undoubtedly of Persian origin.

The gradual rise of the water-table, as it approaches the base of a hill or plateau, is illustrated in Fig. 21, and it is this occurrence which Persian engineers took advantage of. At Aurangabad long infiltration galleries, which may equally well be described as horizontal wells, were dug in the accumulations of talus and soil, lying at the foot of the scarps of Deccan Trap which surrounds the town.

These galleries collect not only water from the water-table but, no doubt, the engineers arranged to collect the seepage from various springs always to be found around the base of Deccan Trap scarps. The water from these galleries were led by underground tunnels, most cleverly excavated by tunnelling in each direction from the bottom of small wells, carefully sunk at intervals, to an exact level, in the direction of the town. On the way to the town the gallery runs for some distance parallel with the Harsul

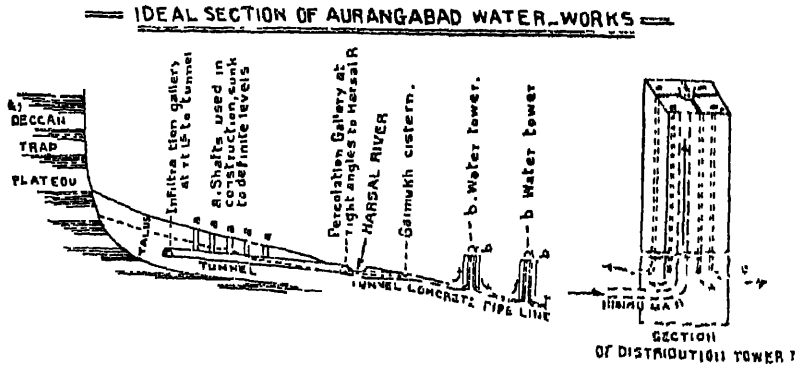


Fig. 21.

nullah, and received more percolation from that source. The gradient of the tunnel is very slight. One main supply, out of fourteen, is still fortunately functioning, in spite of the efforts of past Officers, who did their best to

put them out of action. The water emerges at the Gai Mukh, where it runs into a cistern. From that point the water is piped into the town in crude earthernware pipes set in lime concrete. The engineers here showed great skill and ingenuity. Obviously realizing that their pipe line would not stand the total pressure, if the water was carried down at one stretch to the total fall of the ground to the town, the engineers arranged that the water should be brought up by means of towers to its head and then allowed it to discharge down a parallel down-flow pipe, built into the tower, which connects with the next length of main. Thus any section of pipe line could be repaired by blocking the rising main and, at each of these towers, distribution could be arranged, as described below. When the town was reached, this same principle of water towers was employed for distribution. The central vertical pipe in the tower was the rising main for one of its branches. Built into the tower around the rising main were as many pipes as were required for supplying mosques, cisterns or private palaces, at that point. The top of the central rising main was closed with a brass pot, the bottom of which had been removed, and, around the periphery of the brass pot, were cut slits proportionate in size to the requirements of each distribution unit. These several slits discharged their water into the down-flow pipes, built into the tower leading to the various cisterns, etc. The principle was as simple as it was ideal and well worthy of study, for, as far as the writer knows, no such adequate town water-supply system had been even contemplated in the leading towns of Europe at that period.

The above gives an idea to what great use the water in taluses can be put, but with modern products such as earthenware and cement drain pipes the principle can be much simplified. Figs. 22 and 23 below give two methods of utilizing this water, either by syphon or by cutting a trench and allowing water to discharge.

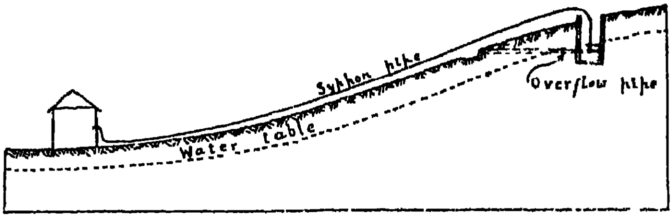


Fig. 22. The syphon used for withdrawing water from a well on a slope above a house An alternative method of obtaining a steady flow, is to carry a pipe outwards from the bottom of the well as shown. (After F. Dixey)

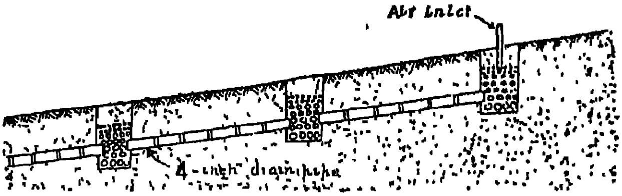


Fig 23. Contour infiltration trenches connected by a single pipe running down the slope. (After U. S. A. Dept Agric.)

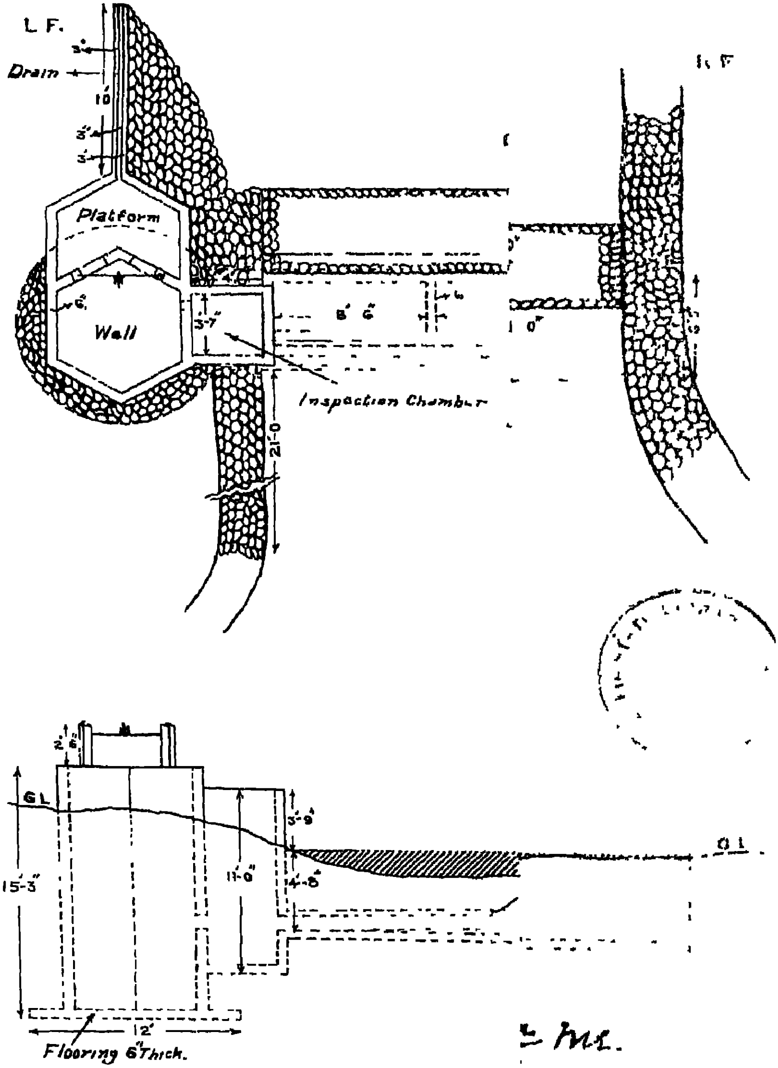
Figs. 22 and 23 illustrate how seepages can be collected on slopes by infiltration trenches, cut at right angles to the general slope of the ground, and each connected to the other by drain pipes, the total collection of water being led into well or underground reservoir.

Percolation galleries dug alongside the banks of streams and rivers, will often give very copious supplies. Tourneaure, in his Cyclopedia for Civil Engineers, Vol. VII, quotes cases where 30,000 to 1,000,000 gallons, per day, having been obtained by this means.

Sub-surface dams or sand traps.

Small concrete walls, laid across beds of sandy nullahs leading to a well sunk above flood level on the bank, are a certain means of obtaining a plenteous water-supply. The writer advocated a series of such dams all down the nullahs of the saline area in Sindhnur Taluq, Raichur District, with the idea of stopping the rain water discharging direct into

TE. No. XI



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the Tungabhadra. It was hoped that, if suitable sites were selected, large patches of sand, saturated with water, would collect on the upstream side of the transverse walls, sufficient to supply an underground cistern on the bank. The writer believes that if only a sufficient number of such sand-traps were made, the downward percolation from these sand-traps would tend in time to reduce the percentage of the salt in the local underground water-table. Two types have been built as shown in plates X and XI the latter designed to sit on a bed of clay, was made to the design of Mr. Asad-ullah, A. M. I. E., the writer's assistant. A full description of these will be found in the Annual Report of the Well Sinking Department for 1340 Fasli.

Should Government decide to carry out this scheme on a big scale, which might be necessary if the Tungabhadra Dam Project is not to be carried out, it is hoped that the expense of such sub-surface dams or sand traps could be considerably reduced by making a careful survey of the nullahs within the saline areas and selecting sites where outcrops of rock cross nearly at right angles to the nullah. After excavating the sand on this line of outcrop down to bed rock, by joining the outcrops by mass concrete, cast between temporary sun dried brick walls, it is thought an efficient and cheap sub-surface dam to bank back the sand could be made.

Meinzer illustrates another method of supplementing the underground water-table in semi-arid regions. In this case, so-called recharge wells are sunk in the beds of nullahs. These excavations fill with water during floods, which otherwise would run to waste, and their contents slowly percolate through fissures, to augment the under-ground water-supply. This practice of artificial recharge of the underground water-table is carried out to a great extent, in the arid regions of the U.S.A., in south-west Africa, French Guinea, and Hawaiian Islands.

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APPENDIX I.

Specimen of Well or Bore-hole record.

No.————

District..................Taluq............Village...........

Field No. ....Height above sea level*................

Depth at which water was first struck.........................

Rate of recuperation............ .For further remarks see back

Feet from Surface	Strata	Remarks	Feet from Surface	Strata	Remarks

* Insert wherever possible, calculated from nearest Bench Mark as in Deccan Trap country it is of vital importance.

Instructions for filling up this form.

It is realised that, often, only maistries are in charge of sinking wells or drills, so therefore, the minimum information only is asked for. In cases where wells or bore-holes are under control of Officers or others, the following subsidiary questions may be kindly answered.

(1) Depth at which water is first struck. Nature of Trap, whether compact and hard or porous or moorum-like? A cigarette tin full of borings from this point, or a sample from well, will be welcomed by the S. O., G. S. D.

(2) If well or bore-hole is started in laterite, was there a large increase of recuperation at junction of laterite and the unaltered Trap?

(3) During sinking or drilling, were any layers of rock such as limestones, sandstones, ash beds etc., encountered? If so, please give depth at which these were first struck and their thickness. Samples will be welcomed.

(4) When any of the above layers struck, was the recuperation greatly improved? Was any sub-artesian effect noticed?

(5) If water is struck under pressure, please report the depth at which it occurred and the rise in the bore-hole, and report the distance to nearest tank.

(6) When well or bore completed, a report on the hourly capacity in gallons, of great importance.

(7) In other strata besides Deccan Trap, samples of borings of rocks, differing from the normal exposed country-rock welcomed; a report on depth at which water was struck and any signs of sub-artesian effects important and cases, where saline water encountered, of great interest.

All relative information about underground water in Deccan Trap (Marathwara) most gratefully acknowledged by the Special Officer, Geological Survey, who will be always glad to answer any queries and if possible arrange for advice after a proper inspection on the site.

L. MUNN.

APPENDIX II

Useful Equivalents.

1 inch of rain yields 22,622½ gallons per acre, and about 14 million gallons per square mile.

1 inch of rain yields about 100 tons of water per acre.

1 inch of rain yields about ½ gallon of water per square foot.

1 inch of rain in a year per square mile would yield if stored about 38,000 gallons per day.

1 inch of rain in a year per acre would yield if stored 62 gallons per day.

1 English acre = 4,840 square yards, or an area of four equal sides of about 69½ yards.

1 cubic foot of water = 6.23, or about 6¼ gallons, and weighs very nearly 62½ pounds (1,000 ounces), at a temperature of about 40° F.

32 cubic feet of water weigh 1 net or short ton 2,000 pounds.

36 cubic feet of water weigh 1 gross or long ton (2,240 pounds).

1 gallon of water weighs 10 pounds.

224 gallons of water weigh 1 ton (2,240 pounds).

The British Imperial gallon equals very nearly $1\frac{1}{5}$ United States liquid gallons; 1 cubic foot equals about 7½ U.S. gallons; and 1 U. S. gallon of water weighs 8.34 lbs.

1 gallon = 4.5449 litres = 0.16 cubic foot.

1 cubic foot = 28.317 litres = 6.228 gallons.

1 pint = 0.563 litres.

1 litre = 1.759 pints = 0.22 gallon.

1 pound = 7,000 grains = 0.4536 kilogram.

1 kilogram = 2.2046 pounds.

1 ounce = 28.35 grams.

1 gram = 0.0353 ounces (av.) = 15.432 grains.

1 yard = 0.9144 metre.

1 metre = 39.37 inches = 3.28 feet = 1.0936 yards.

1 square foot = 0.111 square yards = 0.0929 square metre.

1 acre = 4,840 square yards = 4,049.6 square metres.

1 square mile = 640 acres.

1 square metre = 1.196 square yards = 10.764 square feet.

1 cubic yard = 27 cubic feet = 46,656 cubic inches.

1 cubic metre = 1.3079 cubic yards = 35.31 cubic feet.

Area of a triangle = $\frac{1}{2}$ base $\times$ altitude.

Area of a circle = $\pi \times$ radius^2.

Volume of a cylinder = $\pi \times$ radius$^2 \times$ length.

$\pi = 3.14159$, or approximately $3\frac{1}{7}$

A column of water one foot high exerts a pressure of 0.433 pound per square inch, or 62.352 pounds per square foot.

Degrees Centigrade to degrees Fahrenheit; multiply by 9, divide by 5 and add 32.

Parts per 100,000 into grains per gallon, multiply by 7 and divide by 10

Grains per gallon into parts per 100,000, multiply by 10 and divide by 7.

Grams per litre into grains per gallon, multiply by 70.

Grams per litre into parts per 100,000 multiply by 100.

These equivalents have been abstracted from the appendix to "A Practical Hand book of Water Supply" by F. Dixey (London 1931).

APPENDIX III.

I have to thank Mr. Mukherjee, my senior Assistant Superintendent, for further examining and segregating the available rainfall returns of the Raichur District.

The average annual rainfall is shown in the Table I attached and the graph for this period for each Taluq has been given in Plate I-A.

From Table I, the mean average precipitation in inches in each of the Taluqs for this period is noted in Table II, below, in the order of their relative magnitude. The percentages of the excess over, also the deficiency of rainfall under, the mean average of rainfall of the respective Taluqs, taken from the mean annual average rainfall of each of the Taluqs, are given in separate columns :—

TABLE II.

Taluq	Annual rainfall (in inches: 30 years average)	Percentage of the excess over the mean average of the Taluqs and the number of years		Percentage of the excess over the mean deficiency below the mean average of the Taluqs and the number of years	
	Per cent.	Per cent.	Yrs.	Per cent.	Yrs.
Deodrug ..	26.31	10.30 for	14	12.85 for	16
Alampur ..	23.83	15.61 for	12	15.49 for	18
Raichur ..	21.42	6.27 for	7	23.46 for	23
Sindhnur .	21.09	12.29 for	18	12.12 for	12
Manvi .	20.95	11.34 for	13	10.68 for	17
Gangawati ..	20.42	12.53 for	15	12.41 for	15
Lingsugur ..	20.16	13.54 for	13	13.48 for	17
Kushtagi .	17.78	15.91 for	15	13.95 for	15

From the above Table II, it will be observed that the mean average rainfall of the district based on the average of the 30 years rainfall, calculated from the mean annual averages of the Taluqs, is 21.59 inches. In the same Table

is shown both the percentages above and below the thirty years mean of the rainfall. It may be generally stated that the deficiency below the mean average in each Taluq, has, as a rule, been practically persistent throughout this period. This deficiency in rainfall, is most conspicuous in the Raichur Taluq for the 30 years period under review. Although realizing that 30 years is a short period upon which to base any definite principle, the writer feels that these figures bear out the contention expressed in the body of the text (page 3 *et seq*), that very slow, but a continuous tendency to desiccation is discernable throughout the Raichur District, not only from this examination of 30 years rainfall figures, but also from inspection of high water marks in ancient wells and the past history of the Forts.

The average precipitation, month by month in each of the Taluqs from 1912 to 1931 for 20 years is added, see Table No. III attached.

It is well known that the rainfall of the Raichur Doab is practically confined within the period between June and middle of November, very slight precipitation falling during the remaining months. Although obvious to officers like the writer who have to tour during the monsoon period, until we have many more rain-guage stations, no proof will be available how curiously localized monsoon rainstorms can be. Constantly very heavy rainfall may occur at Mudgal, Maski or Kavital 10 or 17 miles away, or even nearer, and not a drop fall here at Lingsugur, and vice versa. This condition is typical of the monsoon rainfall throughout the district, and in consequence of the limited number of rain-guages very wrong conclusions may now be inferred from the present returns. It also seems essential that annual returns must be calculated from January 1st, not from the end of the Fasli year which breaks the annual monsoon period into two halves. A wide variation in the total average precipitation from month to month may be noted. The statement shows that the largest precipitation of 6.32″ occurred in the month of Aban (September) *i.e.* 7.6 per cent. of the total average annual rainfall. The

months of Amerdad (June) to Azur (October) received the greatest percentage 81.12 per cent. of rainfall and the rest of the months 18.87 per cent. of the total average annual precipitation.

L. MUNN,

SPECIAL OFFICER IN CHARGE,

Geological Survey and Well Sinking Depts.

TABLE I.

The annual average rainfall in inches in the Raichur Doab from 1900 *to* 1930 *for* 30 *years is tabulated as under*.—
(*See Graph I.*)
(*From records of the Statistical Department*)

Year		Alampur	Deodrug	Gangawati	Kushtagi	Lingsugur	Raichur	Sindhnur	Manvi
1900—1	..	19.19	30.29	20.54	11.59	15.68	17.68	17.26	23.74
1901—2	..	17.94	30.26	27.63	17.53	39.08	29.94	21.21	20.49
1902—3	..	20.58	31.68	22.46	17.72	22.28	22.18	22.84	21.74
1903—4	..	22.84	46.23	15.41	7.81	8.10	13.99	11.38	9.83
1904—5	..	13.92	16.28	17.87	14.77	24.64	28.78	23.47	14.44
1905—6	.	20.46	23.69	20.64	10.47	18.25	18.40	22.16	30.98
1906—7	..	20.48	25.43	23.00	21 11	14.16	37.91	25.07	24.85
1907—8	..	12.28	23.87	16.26	12 70	24.16	10.29	13.00	20.32
1908—9	..	16.91	20.59	14.70	10.28	17.59	16.49	13.00	18.57
1909—10	..	16.76	26.61	14.34	10.40	17.89	21.91	24.16	22.62
1910—11	..	31.41	25.76	24.20	32.91	19.56	16.37	18.47	20.90
1911—12	..	20.57	23.97	10.74	7.86	18.91	17.81	13.48	20.15
1912—13	..	22.53	19.65	20.18	18.67	13 47	16.20	22.41	13.77
1913—14	..	24.00	19.96	10.81	16.46	13.69	18.52	25.59	11.43
1914—15	..	34.62	28.64	14.95	23 24	30.98	31.82	34.36	23.88
1915—16	..	25.30	30 36	23.37	23.29	21.31	23.63	22.86	20.75
1916—17	..	44.10	53.43	30.22	48.71	30.79	46.83	37.10	45.79
1917—18	.	46.93	26.60	37.74	26.87	31.35	32.00	22.88	29.44
1918—19	..	16.83	16.35	17.59	18.13	11 30	19.85	15.73	25.31
1919—20	..	30.40	26.50	24.55	22.96	23 45	19.72	25.67	20.70
1920—21	..	16.00	15.28	13.10	19.12	13.47	14.90	17.67	14 98
1921—22	..	24.80	39.10	27.82	20.88	28.40	21.47	17.88	21.[illegible]1
1922—23	..	13.20	15.93	18.10	13.28	16.64	19.92	15.88	18.43
1923—24	..	20.60	14.77	10.68	13.10	11.35	13.23	9.71	18.00
1924—25	..	27.71	22.24	24.49	19.93	17.62	19.70	22.54	17.62
1925—26	..	35.55	32.41	24.26	17.94	20 80	26.24	27.14	25 85
1926—27	..	15.56	22.72	17.77	12 42	14.00	13 74	12 75	18.45
1927—28	..	42.85	34.45	26.75	18.85	22.69	25.49	24.67	28.12
1928—29	..	29.84	33.88	24.81	19.00	31.30	29.44	25.43	26.33
1929—30	.	11.35	13.40	17.74	15 53	19.55	15.18	17.90	24.43

TABLE III

Statement showing the monthly average Rainfall in the Raichur District for a period of 20 years from 1321 to 1340 F. (1912–1931).

Name of Taluqs	Khurdad April	Thir May	Ameradad June	Sherewar July	Meher August	Aban September	Azur October	Dai November	Bhamman December	Isfandar January	Farwardi February	Ardibehist March	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Gangawati ..	00.95	2.36	1.09	2.12	2.15	7.06	3.62	1.14	0.16	0.10	0.20	0.14	21.09
Sindhnur ..	00.56	2.39	2.39	2.33	2.28	6.99	2.79	1.19	0.08	0.17	0.34	0.20	22.25
Manvi ..	00.77	1.34	2.83	3.24	2.91	5.94	3.25	0.68	0.05	0.20	0.24	0.30	21.75
Lingsugur ..	00.56	1.90	2.52	3.03	2.29	5.81	2.90	0.96	0.37	0.20	0.21	0.22	20.97
Deodrug ..	.84	1.59	3.35	5.05	3.34	6.12	2.93	0.55	0.15	0.16	0.17	0.15	24.40
Raichur ..	.63	1.55	3.04	3.61	3.43	5.25	3.18	0.72	0.09	0.20	0.34	0.18	22.22
Alampur ..	.45	1.97	2.98	4.99	4.63	7.07	3.15	0.94	0.22	0.22	0.39	0.15	27.16
Average ..	0.68	1.95	2.60	3.48	3.00	6.32	3.12	0.88	0.16	0.18	0.27	0.19	22.82

APPENDIX IV

A NOTE ON THE CORRELATION OF THE DECCAN TRAPS TO UNDERGROUND WATER IN PARTS OF OSMANABAD DISTRICT,

By

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Please read with reference to attached Sections and Map.

CONTENTS.

A NOTE ON THE CORRELATION OF THE DECCAN TRAPS TO UNDERGROUND WATER IN PARTS OF OSMANABAD DISTRICT

(BET.-LAT:-17°-0'-0";18°-30'-0"&LONG:-75°-20'-0";77°-0'-0")

Introduction

During the close of 1931, the Special Officer made a rapid tour in parts of Gulbarga and Osmanabad Districts and came to certain tentative conclusions regarding the nature of the Deccan Traps of the area. Visualising the possibility of correlating the distribution of underground water to the geological structure, he deputed the writer to go over parts of Gulbarga and Osmanabad Districts and make a detailed study of the Traps with this object in view. The field-work was commenced at Shahabad in Gulbarga District, very near the junction of the gneisses, the Vindhyan limestones and the Deccan Traps and continued towards and around Gulbarga, up to Kamlapur, on Gulbarga-Homnabad road. As no clear natural section of the Traps could be made out in the neighbourhood of Gulbarga, the work was continued from Naldrug, through Tuljapur, Osmanabad, Vadgaon, Barsi, Parenda, Mankeshwar, and Bhum, in proximity to which route, good natural sections or road and railway cuttings are exposed.

General Geological considerations.

The following excerpts in extenso on the Deccan Traps from Capt. L. Munn's book on the "Geology of the Underground Water Resources of H.E.H. the Nizam's State," written specifically to make the subject intelligible to the layman, will help the reader to appreciate the full significance of the correlation drawn by Capt. Munn in the Trappean formations, between the geological history and the distribution of underground water, which is exemplified in this note from detailed field-work.

".... Deccan Trap," he writes, "is the remains of what was once a far greater spread of vulcanic lava. Through the course of geological ages it has been enormously worn away, for traces of it are found as far south-east as Rajahmundry, showing that once

probably the whole of the Nizam's Dominions was covered with this vulcanic lava. Stretching as it did at one time from Sind, it must have once covered an area of at least half a million square miles. Even to-day, in its denuded condition, the present existing lava spread of the Deccan Trap comprises 2,00,000 square miles and is the greatest known spread of vulcanic lava in the world Of the above area 32,000 square miles lie within the State limits

"For how many millions of years this period of vulcanic activity continued can only be conjectured, though it must have been enormous as the greatest thickness of these vulcanic lavas is now nearly 10,000 feet

"During the era frequent periods of extended quiescence occurred, these periods were of such great length that the molten lava had not only time to cool, but vegetation started again, pools and lakes were formed, normal pond life, fishes, frogs, and vegetation existed, and insects flew over the ponds. All this we know from the fossil remains. During this period of quiescence disintegration of the surrounding area was in progress through rain and other normal causes, and partially filled the lakes and pools with mud, burying the discarded shells of the molluscs, dead frogs and fishes just as happens in a big tank to-day.

"The study of these rocks shows that suddenly the scene changed and with awful swiftness, perhaps without warning, another vulcanic outburst occurred, and similarly, as happended in Gautemala in 1929 a fresh wave of red hot, highly liquid lava, rolled over the landscape obliterating and burying everything beneath its terrible onrush. From geology we also learn that the process of vulcanic outburst at times changed from the welling-out of highly liquid molten lava from vents, and for a period vast masses of ashes, and scoria were ejected, which we now find as interbedded ash-beds between the layers of ancient vulcanic lava.

"A casual examination of these layers of lava, exposed in cuttings and escarpments, shows that they have cooled and weathered in very distinctive and different ways

"But, before any start is made in the examination of these lava flows, the reader must more fully realize the vulcanic process, and it must be the writer's endeavour to explain the probable sequence of events so clearly that they become practically vizualized to his imagination.

"The reader must attempt to speculate huge deep long rents suddenly forming the continental crust, so deep as to give release to the underlying magma, the compressed molten lava, on which our continents rest, or float The pressure thus released would allow the molten matter to well up to the surface at a temperature of some 1,200° C, and pour out like white hot fluid metal over the surrounding country. Some cause stops the flow of lava, and, for a period, just

as occurs to-day in the vulcanic areas of the world *e.g.* in Japan, and at Vesuvius and Etna in Europe, a period of quiescence of unknown and uncertain length follows.

"The thickness of the hot lava that has flowed out from the vent will vary in each eruption according to its magnitude and duration. The lava layer will cool rapidly and owing to its nature, will immediately start to contract and become fissured. This process would be specially assisted if the overheated surface were suddenly quenched and chilled by heavy downpours of rain, which frequently accompanies such vulcanic disturbances Then the period that elapses between the first and the following outflows decides the amount of surface disintegration and denudation, that each special individual layer undergoes.

"For reasons, not yet fully explained, each succeeding outflow of white hot magma is not always of the same chemical composition and, as stated above, probably for this reason, besides others, their structure after cooling owing to sudden contraction, assumes many different aspects.

"The reader must clearly grasp the fact that these outpourings of molten lava did not always start from the selfsame vent, not even from the same locality and, at times perhaps, several vents were functioning at the same time. This will account for the reason why in one area we may find the sequence in the order of lava layers consistent throughout, whereas in another area, but a short distance away, the sequence may be entirely changed, though perhaps having some recognizable layers in common." This is clearly portrayed in the accompanying section, if read in conjunction with the map.

Methods of study.

As the object of the work was to segregate the correlation of the geological strata and the distribution of underground water, the sequence and thickness of the flows had to be clearly studied. A Watts & Son's surveying aneroid 3" diameter with vernier adjustment, capable of reading correct to the foot, was found most helpful for the purpose. Generally, at every camp, the hourly barometric variations during the day, for two or three days, were determined. It is found that even during the hot dry season before the monsoon, the difference between the extreme readings in 24 hours would be as much as 100 ft. or even more. A study of the barometric variation graph at each camp indicated the tendency of the diurnal variation. An absolute correction for the daily

use of the barometer even in that camp could not be deduced, as the variation differs from day to day, even during the corresponding hours. Usually, the altitude of the camp was determined accurately with the help of the barometer, from the nearest G. T. S. Trig. point, Bench-Mark, or intersection point, after making the necessary correction. Thus the camp was always one point of reference for barometric correction. Then if the work entailed stopping at the same place for any short time interval, as even 10 or 15 minutes, the barometric variation during this period was noted and the rate of rise or fall of the barometer during that part of the day could be deduced for the correction. If any G. T. S. Trig. point, Bench-Mark or intersection point was near by, the barometer was further calibrated with reference to that point and the correction carried out accordingly. By a judicious use of such methods, it seems, that during non-monsoonic seasons, altitudes could be determined with a good surveying aneroid with a sufficiently fair degree of accuracy for the purpose of the enquiry.

While recognising the great utility of the aneroid for geological work of this nature, it is well to remember the limitations and occasional elements of uncertainty in this method of computing altitudes. A sudden atmospheric eccentricity is not an unusual phenomenon; sometimes, a strong jerk or shock received by the instrument vitiates the degree of accuracy of the readings. There are other practical difficulties which need not be enumerated here.

In a few places, while taking transverse sections, necessitating levels perhaps every hundred yards, the Abney's level was used for deducing the levels as no Indian clinometer was available. As this process entails chaining the whole distance, thus impeding the rapid progress of work, this method was resorted to only on necessary occasions. The aneroid is generally found to answer the purpose satisfactorily if used with constant checks and calibrations.

The altitudes and sequence of the various beds of the Trap flows exposed in the natural cuttings, nullahs, ghat

roads, etc., were initially noted Then, logs of well sections, in each area were recorded. In the following paragraphs, the summary of such an enquiry are recorded and the whole enquiry clearly illustrated by the attached sections.

Naldrug

Naldrug is a small town on the bank of Bori river, with a beautiful ancient fort. Several natural sections on the river bank may be found in the neighbourhood. The following sections noted about 2 miles and 4 miles south of Naldrug give the order of sequence of the flows between 1,745 ft. and 1,655 ft. sea-levels.

TABLE I.

A hillock near the junction of Khandal nullah and Bori river, 4 miles south of Naldrug.

1,700′—1,685′	Bedded, jointed rock, in parts, exfoliating.
1,685′—1,670′	Much jointed, decomposed rock and mooram.*
1,670′—1,655′	Bedded, jointed non-exfoliating rock.

TABLE II.

Vertical section by the side of Bori river, 2 miles south of Naldrug.

1,745′—1,697′	3 layers (the junction being masked by talus) an upper bedded, jointed rock, a middle exfoliating, and lower jointed rock.
1,697′—1,678′	Bedded, jointed rock, in parts exfoliating.
1,678′—1,665′	Much jointed, decomposed rock and mooram.
1,665′—1,654′	Non-exfoliating, bedded, jointed rock.

* The term 'Mooram' is here loosely used to denote a much decomposed rock which does not retain its original characters and is nearly completely altered. It is often pink or red with various shades of these colours and frequently contains the secondary minerals such as stilbite, apophyllite, heulandite, natrolite, calcite, which go by the name of *zeolites*. Mooram in which these zeolites are frequent are described as *zeolitic mooram*. They are quite porous and are often hardened. These hardened zeolitic mooram layers are generally good aquifers.

Slight local structural disturbances are noted in the disposition of the layers near Naldrug. Between Naldrug and Shahpur 7 miles due south, there are a number of wells, mainly for purposes of irrigation. Some of the best wells, *i.e.* those affording a good supply of water, may be enumerated here. The Tulsiram and Ramji Patel wells in Guznur, which are each said to supply water for two mhotes all through the year and the Gai Mukh well in Wagdari are seen to be between 1,670′ and 1,700′ levels, with the water level in the mooram layer, between 1,670′ and 1,685′. At Shahpur village, 7 miles due south of Naldrug, (general ground level 1,644′), due to the absence of water-bearing layers up to now untouched by wells, there is water famine in summer months. It may be seen that the prolific wells are all situated in decomposed lava and mooram.

Tuljapur

Tuljapur is the taluq headquarters with a constant floating population on account of its attraction as a place of pilgrimage to the Hindus. It is just on the brink of the 2,000′ plateau. Several sections of the Trap flows may be seen in the neighbourhood. A good section of the Trap country between 2,100′ and 1,650′ may be observed along the Osmanabad-Sholapur trunk road, between the 15th milestone near Tuljapur and Malumbra and beyond. A transverse section was taken along this road from 14th milestone to 22 m. 3 f., stone S.S.W., of Malumbra—from 2,070′ to 1,658′ levels. A separate note on this has been submitted. The sequence of the successive lava flows as noted while making the transverse section, is given below :—

TABLE III.

Section along Tuljapur-Sholapur road.

2,070′—2,052′	Bedded rock, highly decomposed along joints.
2,052′—2,033′	Moderately compact, bedded rock, some decomposition in joints.

2,033′—2,013′	Massive bedded rock, only surface weathers red.
2,013′—1,962′	Two layers of mooram—an upper red and a lower pink-violet zeolitic.
1,962′—1,943′	Compact, typically exfoliating rock.
1,943′—1,930′	Bedded rock, highly decomposed along joints.
1,930′—1,905′	Friable mooram.
1,905′—1,881′	Compact, typically exfoliating rock.
1,881′—1,856′	Hardened zeolitic mooram.
1,856′—1,840′	Massive, compact rock, only surface slightly weathered.
1,840′—1,822′	Exfoliated rock in decomposed matrix.
1,822′—1,801′	Mooram with rare exfoliating boulders.
1,801′—1,770′	Two layers of mooram.
1,770′—1,762′	Highly jointed, non-exfoliating rock
1,762′—1,749′	Red mooram.
1,749′—1,740′	Jointed, bedded rock.
1,740′—1,728′	Hard, compact rock.
1,728′—1,715′	Compact, exfoliating rock.
1,715′—1,700′	Bedded, jointed rock.
1,700′—1,680′	Jointed rock, exfoliating.
1,680′—1,665′	Jointed, decomposed rock and mooram.
1,665′—1,652′	A highly bedded, non-exfoliating rock.

Where the exposures were not observable along the line of section, the sequence of the beds have been deduced from examination of the sides of the wells in the vicinity. Another instructive ghat section may be met with on the way to Apsinga, 4 miles north-north-west from Tujlapur. The following sequence of the beds noted during the traverse is tabulated here.

TABLE IV.

Section 1 mile S.S.E., of Apsinga, along Apsinga–Tuljapur track.

2,150′—2,127′	Jointed, compact rock, in parts exfoliating.
2,127′—2,095′	Jointed, bedded, much decomposed rock.
2,095′—2,076′	Exfoliating boulders and zeolitic mooram.

2,076′—2,052′	Bedded jointed rock.
2,052′—2,030′	Two layers of jointed rock.
2,030′—2,015′	Bedded, compact rock.
2,015′—1,980′	Red and pink zeolitic mooram.

Tuljapur town is subjected to severe water famine in spite of the fact that there are not less than about forty large wells and several smaller ones. The water-level in the town proper was from 40′ to 50′ below the ground-level during April and the recuperative power of the wells is said to be poor. A reference to the tables 3 and 4 shows that between 2,060′ and 2,015′ levels, there are no layers capable of acting as good aquifers. The layers below 2,015′ down to 1,970′ are seen to consist of what is described as 'zeolitic mooram.' The Pachunda well, a mile east of Tuljapur, which supplies water to Tuljapur town in severe drought, is excavated in zeolitic mooram between 1,990′ and 2,020′. The Pachunda well is unlined exposing a good section in the sides. Below soil and kunkar, is a thin layer of hard jointed rock, under which, the zeolitic mooram layers are clearly visible. These mooram layers are the water-bearing strata. Though the wells in Tuljapur have gone much deeper from ground-level, they have not penetrated this layer of mooram sufficiently deep to ensure a good supply of water. Besides this, there is the physiographic factor of the situation of the town of Tuljapur right on the edge of the 2,000′ plateau. The extent to which this feature affects the retention of underground water has also to be taken into consideration.

Wells around Tuljapur.

Just due south of Tuljapur, at the foot of the hill, is a well excavated some seven or eight years ago, which is said to be perennial and supplies a betel-leaf garden. An examination of the sides of this well reveals the fact that below a layer of exfoliating rock is exposed a bed of compact zeolitic mooram in which may be seen the aquifer. This layer is between 1,855′ and 1,880′. A reference to Table 3 (and to the section) indicates that this corresponds to the hard zeolitic mooram layer below an exfoliating bed,

between the above sea-levels. Several good irrigation wells, such as Bhagavan Mali's well, in Apsinga, about 4 miles N.N.W., of Tuljapur, draw their supplies from the same zeolitic mooram layer.

The groups of wells in Sindphal, near the 16th milestone, Osmanabad–Sholapur trunk road, are sunk between 1,770′ and 1,805′ layers. In Dekhri village, about 3 miles N.W., of Tuljapur, good irrigation wells are found drawing their water supplies from between the same sea-levels, all from the same zeolitic mooram layer. Thus, the villages of Sindphal, Dekhri and Apsinga are thriving and prosperous due to their being located at elevations quite favourable for tapping a good supply of water at convenient depths from the general ground-level.

Though several wells may be noted between 1,770′ and 1,660′ between Sindphal and Malumbra and beyond, they dry up in summer, due to their having been excavated only in comparatively more compact beds of the trap. With a judicious selection of a site if only slightly deeper sinking was carried out perennial water at a moderately shallow depth would undoubtedly be struck.

Osmanabad

Osmanabad is the headquarters of the district, about 12 miles due north from Tuljapur town. A fairly good natural section may be noted in the Siddheswar temple valley, west of the 5th milestone on the Osmanabad–Sholapur road, near Wadgaon. The sequence of the flows, as noted in the Siddheswar temple valley is tabulated below :—

TABLE V.

Section in Siddheswar Temple valley.

2,160′—2,145′	Bedded, compact rock.
2,145′—2,127′	Exfoliating layer.
2,127′—2,086′	Highly jointed rock, much decomposed in parts.
2,086′—2,070′	Zeolitic mooram.

Another natural section, studied from Osmanabad camp was in the neighbourhood of the Lena caves, about 2 miles north-west of Osmanabad.

TABLE VI.

Section at Lena caves.

2,257′—2,239′	Jointed rock, in parts exfoliating.
2,239′—2,208′	Non-exfoliating, jointed rock.
2,208′—2,185′	Jointed, much decomposed rock.
2,185′—2,157′	2 layers of zeolitic mooram.
2,157′—2,126′	2 layers of rock, the upper layer being jointed and compact and the lower layer, exfoliating. The junction of the layers cannot be clearly defined, due to talus cover.

Attention may be drawn to the similarity of sequence of the corresponding lava-flows in the neighbourhoods of Tuljapur and Osmanabad, two places situated as far apart as 12 miles.

Wells and water-bearing strata in Osmanabad town.

Osmanabad town does not suffer much from water famine, except in the severest drought. This seems to be due to the fact that under a thin mantle of harder rock, are to be seen, the softer, more porous layer (the zeolitic mooram layer beds) between 2,155′ & 2,185′. In the bed of the nullah which runs through the town are seen several springs. All these springs in the bed of the river are located in the zeolitic mooram layers. The irrigation well of Gafoor Sahib, in which is installed a centrifugal pump, is also sunk to about the same level (2,155′—2,185′) exposing the soft, decomposed mooram layers in the sides. The well has gone down right to the base of the mooram layer. Besides these, several wells were examined in the town proper; the aquifer in all these cases is the zeolitic mooram. In some cases wells have been sunk below that layer, and have penetrated compact rock.

During the course of the field-work, two bored-wells were examined in Osmanabad town. It may be mentioned here that the town of Osmanabad is built on the sides of a valley, the difference between the highest and the lowest parts of the town being quite as much as 50′–60′. On account of this feature, the problem of drainage of the town becomes highly complex. The instance of the bored wells in question exemplifies how an absence of the proper appreciation of the geological conditions of the sub-stratum has led apparently to anomalous results in the same town.

Bored tube wells in Osmanabad town

The Sowcar's bored well, situated in the highest part of the town which is on about 2,220′ level, and is said to have been drilled to a depth of 100′ below the ground-level. This reduces the depth of the bottom level of the bored well to 2,120′. It does not tap an aquiferous layer, but penetrates into a bed which is decomposed and much jointed; perhaps capable of retaining water in the wet weather but not in drought. The owner considers it a failure. The bored well belonging to Ebrahim Sait is adjacent to the nullah, where the ground-level of the collar of the tube well is about 2,170′. The depth of the bored-well is said to be about 90′. Reducing the level of this second bored well, the bottom level of the well works out to 2,080′. It will be seen from Table 4 and the Section, that this is the level of the zeolitic mooram-like layer, a rich water-bearing strata. The owner meets with adequate supply of water all through the year. The Sowcar wondered why he had not got enough supply in his bored well, even though it has gone to a depth of 100′, whereas, another person was luckier, going down only 90′, in the same town. When it was explained to the Sowcar that the general ground-level of his locality was about 40′ higher than the ground-level at Ebrahim Sahib's well and that though the Sowcar had gone 110′ from ground-level he had still not gone deep enough to tap the water-bearing strata which happened to be penetrated by the 90′ bore of Ebrahim Sahib's well, he quickly grasped

the simple reason for the anomaly. This instance is detailed here to emphasise the necessity of understanding the geology of the sub-stratum while tackling problems of underground water resources. This is a clear instance of how useful our research will be to the Boring Superintendent of the Agricultural Department.

Perennial wells around Osmanabad.

In the Siddheswar temple is a well called "Chakradhara" which is said to be perennial affording adequate water to the thousands of pilgrims who are said to muster for a fair in summer. The ground-level of the collar of the well is at 2,109′, the aquifer being between 2,090′ and 2,070′. From a reference to Tables 4 and 5, and the Section it will be seen that this is the zeolitic mooram like layer.

The perennial wells in Vadgaon are between 2,160′ and 2,190′ in the mooram layers (vide Table 6). The Lena caves are excavated in the mooram layers between about 2,160′ and 2,190′ levels. Several cool springs in the caves, even at that edge of the tableland, hold from time immemorial the reputation of being perennial. The Kapildhara is a perennial spring about 2 miles west of Osmanabad, between 1,995′ and 2,000′, in zeolitic mooram layers, (vide Table III). This is said never to have dried up and water from this spring is utilised for purposes of irrigating some lands lower down the valley.

The country between Osmanabad and Vadgaon is soil-covered and few sections are exposed where the sequence can be studied to any appreciable extent.

Vadgaon.

Good sections of the Trap country from 2,400′ to 2,000′ may be seen in the neighbourhood of Vadgaon. Some typical examples are tabled below :—

TABLE VII.

Vertical section in the neighbourhood of G. T. S. Trig. stn (2,248′) Bonadevi. 2 miles N.W., of Vadgaon.

2,245′—2,222′ 2 layers of decomposed rock.

2,222′—2,208′	Jointed rock, exfoliating in parts.
2,208′—2,187′	Jointed rock, weathered in parts.
2,187′—2,160′	Hardened zeolitic mooram.
2,160′—2,144′	Compact, jointed rock.
2,144′—2,117′	2 layers, (junction talus covered) an upper jointed exfoliating and a lower exfoliating rock.
2,117′—2,090′	Decomposed rock, much jointed.

The section is taken from Bonadevi hill down a nullah running westward, towards Ukadgaon.

Some sections 5 miles north-west of Vadgaon, near the Edai temple, (Yermala) give the sequence of the flows between 2,400′ and 2,300′ levels.

TABLE VIII.

Section between the Edai Temple and a well in the valley.

2,360′—2,348′	Exfoliated rock.
2,348′—2,322′	Red friable mooram.
2,322′—2,305′	Compact pink mooram with occasional exfoliating boulders.
2,305′—2,291′	Jointed, bedded rock.

TABLE IX.

Another section from the Edai temple to the foot of the hillock on which is situated the temple.

2,393′—2,380′	Jointed rock, in parts exfoliating.
2,380′—2,360′	Brown, friable decomposing rock.
2,360′—2,345′	Exfoliating rock.
2,345′—2,305′	2 layers of mooram, an upper red and a lower pink mooram.

Another good section near Ramling temple, about 3 miles south of Vadgaon may be studied with advantage.

TABLE X.

Near Ramling Temple.

2,200′—2,187′	Jointed rock.
2,187′—2,160′	Red mooram, lower layer, highly decomposed, mooram-like and weathered rock.

2,160′—2,140′	Jointed rock.
2,140′—2,130′	Exfoliating rock.
2,130′—2,117′	Massive, jointed rock.
2,117′—2,089′	Much weathered type, with exfoliating boulders under which, begins just, a zeolitic mooram layer.

It is again of interest to note that the corresponding Trap-flows both around Osmanabad and Vadgaon show the same order of sequence, though separated by a distance of about 15 miles. The similarity of the strata over a wide area to which the Special Officer drew attention in his description of the Deccan-Traps (loc. cit) is clearly exemplified from the above observations.

Perennial wells around Vadgaon & in the neighbourhood.

Mitchuraski's well about a furlong east of Yermala is a good irrigation well. The bottom of the well is 30′ from the ground-level which is at 2,335′above sea level. The unlined sides of the well expose friable red mooram and a lower harder pinkish mooram-like layer. The well is said to be about the best around Yermala. A reference to Tables 8 and 9 shows that this level coincides with the mooram layers between 2,305′ and 2,345′. At Chorakhali are several good wells. The ground-level of the Nagjheri belonging to the Mali-patel is at 2,191′ and a little below the ground-level may be seen zeolitic mooram, which is said to extend to the bottom of the well, *i.e.*, to 1,265′ level. We see at once from a reference to the Table VII, that this corresponds to the zeolitic mooram layer between 2,160′ and 2,187′. Ramnarain's irrigation well south-east of Chorakhali is another good irrigation well, with stone lining. The ground-level is at 2,204′ and water-level is 12′ below ground-level and the aquifer is 26′ below G. L. *i.e.*, between 2,190′and 2,164′. This, as will be seen from table VII, is the same 2,187—2,160′ zeolitic mooram layer.

The perennial spring near Ramling temple is at the 2,080′ level in pink mooram layer. (See Table V) Several irrigation wells in Demarvadi are between 1,930′

and 1,900′ layers. As may be seen from the Table, this corresponds to the friable mooram layer between 1,930′, and 1,905′. It may incidentally be remarked here that the friable mooram does not seem to be quite as good an aquifer as a hardened zeolitic layer. In Cincholi, some irrigation wells support good cultivation. The water-level in most of these cases are between 1,801′—1,820′ in zeolitic mooram layers.

Barsi and environments.

The 2,200′ plateau forms roughly the north and north-eastern boundary of Barsi taluq and steps down almost, abruptly, towards the west of Yermala, Vadgaon and Ramling, to the 1,800′ contour. A great part of Barsi taluq is between 1,600′ and 1,900′ contours with few prominent hills or ridges. Natural sections and vertical cliffs are almost rare, though the study of wells and other minor cuttings afford interesting data.

In the town of Barsi itself, may be seen scores of wells, most of them are perennial and water-level in all the cases is between 1,660′ and 1,680′ levels, in mooram. We see from a reference to the Tables 1, 2 and 3 that this is the layer of much decomposed rock and mooram. In some of the irrigation wells, the section is well exposed and the decomposed mooram layer can be easily identified at and below the water-level. The big well in Lokamanya Cotton Mills is about 100′ long and 30′ broad and the water-level is 15′ below the ground-level; the unlined sides expose zeolitic mooram and decomposed friable rock, under a mantle of soil and kunkar. It is said to be quite adequate for all the requirements of the mill. The Pangri railway well is a perennial source which supplies large quantity of water to the locomotive engines at the Pangri watering station. It seems to be in soft mooram, probably corresponding to the layer between 1,749′ and 1,762′. Between Pangri and Kuslamb, several irrigation wells may be met with, between 1,700′ and 1,750′ but these are said to dry up in times of drought. South of Kuslamb, towards Dhotre, may be seen irrigation wells, with the aquifer

between 1,770′ and 1,800′. The sides expose zeolitic mooram and the wells are said to have good recuperation. On the Barsi-Sholapur road, very few wells are seen between 1,680′ and 1,650′. Near the 40 m. 4 f. stone on the Sholapur–Barsi trunk road is a well between 1,655′ and 1,675′ which is said to yield water for drinking purposes even during drought. The mooram beds in the sides of the well composing the aquifer, can be seen easily, (see Table III). Some good irrigation wells south of Pangaon (5 miles south of Barsi, Barsi–Sholapur trunk road), are between 1,660′ and 1,680′, in mooram. At Virag, further on the same road (15 miles S-S-E of Barsi), the wells are only sunk to between 1,580′ and 1,625′ and the well sections expose only bedded compact rock to great depth. in consequence the place suffers from water scarcity all through the year. Going west-ward from Barsi for about 4 miles, towards Parenda, on either side of the road for Barsi, we seem to recognise the sequence of the beds to be in conformity with what has been observed along the Naldrug, Tuljapur to Barsi Section. Thus correlation of the beds and identification of the aquifers has been clearly proved over a length of 60 miles. Beyond this point, as we approach Parenda, the characters of the lava layers are entirely different.

We are now entering a separate volcanic zone. This fact expresses itself in several indirect ways. The soil is much more loamy here, with a reddish tinge. Amorphous silica is developed in profusion in almost every layer. The zeolitic beds are not so prominent here as in the other area.

Parenda and Kukedgaon.

Round about Parenda, very few natural sections are exposed where the sequence of the beds of the Trap flows can be noted In the absence of natural cuttings of any appreciable thickness, the succession of beds in this area can only be deduced from logs of well sections and other minor cuttings. The following sequence is thus deduced from the data afforded mostly from well sections.

TABLE XI.

Sequence of the beds of the trap-flows around Parenda–Kukedgaon.

1,900′—1,880′	Bedded, jointed rock.
1,880′—1,865′	Highly decomposed rock, mooram in parts.
1,865′—1,847′	Exfoliating rock.
1,847′—1,835′	Bedded jointed rock.
1,835′—1,820′	Exfoliating rock and mooram with zeolites.
1,820′—1,802′	Typically exfoliating rock, in places, bedded.
1,802′—1,785′	Bedded, jointed rock.
1,785′—1,765′	Exfoliating layer.
1,765′—1,747′	Much jointed, decomposed type.
1,747′—1,724′	Jointed, bedded rock with abundant amorphous silica.
1,724′—1,696′	Red zeolitic mooram-like layer.
1,696′—1,683′	Zeolitic mooram ?
1,683′—1,673′	Jointed rock, in parts exfoliating.
1,673′—1,650′	Red, hard mooram, with calcite and some zeolites.
1,650′—1,634′	Exfoliating rock.
1,634′—1,617′	Mooram with occasional exfoliating boulders.
1,617′—1,602′	Red fine powdery mooram.

It has to be emphasised, that as it is only possible to construct the above section from observations from the well sections, slight variation in the thickness of the beds, or of their nature, may be possible Even allowing these possible errors the sequence of succession of the Trap-flows is fairly satisfactory, confirmatory logs were obtained from the widely distributed wells noted in this taluq.

We see from a comparison of the section around Parenda with the sequence noted in the neighbourhood of Naldrug, Osmanabad, Vadgaon and Barsi, that the succession and nature of the beds around Parenda are entirely different from those noted around the other places. The most remarkable feature noted even from superficial observation around Parenda is the abundant development of amorphous

silica in its various forms in almost all the layers, and the frequent spreads of red loamy soil in contrast to the B. C. soil which characterises the other area. Green incrustation in the zeolitic mooram-like layers is another special feature around Parenda. Due to greater porosity of the soil here, moisture is not retained for a long time and irrigation wells become a dire necessity for cultivation.

Several good irrigation wells between Deogaon and Shiral are between 1,650′ and 1,673′ in zeolitic mooram-like layers; between 1,683′ and 1,724′ the layers of mooram-like and decomposed rock with or without zeolites, act as good aquifers. Several wells in Parenda town and in Javla, about 10 miles E.N.E., of Parenda, typically illustrate this condition. Between 1,750′ and 1,765′, a much jointed and decomposed type is the water-bearing strata. The perennial wells in Kandari, about 7 miles north of Parenda, are situated at this level. The zeolitic mooram-like layers with exfoliating boulders and highly decomposed rock types between 1,800′ and 1,835′ act as aquifers. The perennial wells at Kukedgaon, Karala, Ekburzwadi and Vale, (all north of Parenda), are situated between these layers.

Mankeshwar.

At, and in the neighbourhood of Mankeshwar, the well-sections expose abundant kunkar in the top-layers. Lower down, may be seen in some of the deeper wells, kunkar with water-worn pebbles and boulders in the matrix. These kunkar beds are about 30 or more feet thick and can be traced along the well-sections up to Shekapur.

It is not intended here to go into minute details of the geological significance of the occurrence of these different zones, each showing a particular succession of the Trap-flows. This has been lightly touched upon in the opening paragraph of this note. From the presence of the thick beds of kunkar around Mankeshwar, and the prominent development of the pink and ash-coloured mooram-like layers near Ashta, 4 miles N.N.W., of Mankeshwar, it seems probable that the boundary of the two flows, *viz.* the flows exposed in sections from Naldrug to Barsi and this Parenda-

Bhum area, may be roughly drawn from Bhum through Mankeshwar, Sirsav, to Uplai, about 2 miles south of the 11th milestone Parenda–Barsi trunk road. The absence of good natural cuttings greatly handicap in the study of the area. Places situated to the east of Bhum–Mankeshwar -Sirsav line seem to belong to the first mentioned series of trap-flows. No reliable sequence can be made without a core drilling at several points.

General discussion.

As was pointed out earlier, this field-work was conducted with the main object of trying to under-stand the relationship of the distribution of underground water to the geological formations. The methods of study followed to elucidate this point have been briefly described in the opening paragraphs of this note. From the results which have been tabulated and described, attention may be drawn to a few salient points. A word of explanation seems necessary with regard to the nomenclature used in describing the various beds of the Trap-flows; in natural sections as well as in other cuttings, the successive layers can be easily identified from certain general characters which extend over the whole area where the sequence noted holds good. The names given here are purely descriptive, based mostly on weathering and do not have any petrological significance. Locally, it is not unusual to find a combination of two or more types of weathering exhibited in the same layer, but this is only an exception and each layer generally shows some characteristic type. The contacts between the layers are usually well-marked and sharp. Sometimes, we see greater alteration of the layers in the immediate vicinity of the contact planes. Rarely, these attain a thickness of 3′ or 4′ and simulate a thin flow of Trap. A close examination of the rock however establishes its identity.

Horizontality of the flows.

The horizontality of the flows over extensive areas may be actually seen on the edge of the table-lands; for several miles, as we walk along the foot of the 2,000′ tableland, these successive beds can be easily traced and followed. Dips

as such are very rare, or absent, though here and there, some disturbance in the disposition of beds may be noted purely due to local causes. Such dips are seen, for instance, at Kesar-Kadaka, Ramtirth and several places near Naldrug. Very probably the anomalies observed near Naldrug in the thickness of the beds may be due to this reason. Similar disturbances may be noted in a few places on the Tuljapur ghat road, in the Siddheshwar temple valley 5 miles south of Osmanabad, in parts of the ghat road and railway cutting between Vedshi (Yedsi) and Demarvadi. Sometimes, the junction of the plane of the two beds is not perfectly horizontal but shows a wavy surface. This presumably must be due to erosion of the layer before it was covered by the succeeding Trap flow. Occasionally, we also come across cases of 'invasion' of one bed into another. Thus, lenticles of exfoliating boulders may be seen in a layer where the rest of the formations may be compact, jointed rock. Such examples are typically observed in the Yedsi-Pangri ghat road. In a well section, for instance, in Demarvadi village, the sides consist of exfoliating boulders on one side and typical zeolitic mooram-like layer on the other at the same level. Without going into the details of the causes of all these here, it may be merely remembered that these factors have to be borne in mind when apparent anomalies are met with in any locality. Generally speaking, the disposition of the beds is horizontal and generalisation of the distribution of underground water with regard to the sequence of the flows has been proved to hold good roughly from south to northwest over a length of 60 miles. It now remains to find the total area over which these conditions hold true.

The relationship of the water-bearing strata to the Trap-flows.

Logs of well-sections bring out the fact that usually, the zeolitic mooram-like layers are good aquifers and that wells excavated into these layers afford good recuperation and supply. Deducting the level of the well sections from barometric observations and comparing them with the sequence

of the beds as noted from natural and other cuttings, we find the identity of the beds at about the same altitude above the sea-level. This observation warrants our assuming that the nature and sequence of the beds noted at the margins of the tablelands also continue right through the whole area. A reference to the attached section clearly brings out this feature. From the results enumerated, it is seen that the hypotheses formulated by Capt. L. Munn regarding the correlation of the distribution of underground water with the geological history in the Trappean formations are amply borne out by the data deduced from field-work.

Nature of the flows.

The Deccan Traps are basic lavas of more or less uniform composition. It may be asked, why in spite of this fact, such wide variations in their physical characters are met with. Some are compact and bedded, others show spheroidal or exfoliated weathering, and quite frequently we meet with layers which are loose and friable, or hardened mooram like layer with a rich association of zeolites—a group of secondary minerals derived in the alterations of some kinds of basic lavas. An occasional find of pumice remnant in the zeolitic mooram-like layer is of special significance. All these features will be dealt with in the part dealing with the petrological aspects of the formations. These differences in the nature of the flows seem to be due to the variations in the conditions attending each effusion and no doubt, to the period they had been exposed to the agencies of denudation before they were covered by the next flow. It has also to be determined to what extent the slight differences in the mineral constitution are the contributory causes. As yet, no systematic work has been carried out to work out the geological history of the Deccan-Traps. A detailed discussion of all these will form the subject-matter of a latter contribution after more work has been done both in the field and in the laboratory.

The distribution of water underground is a function of several complex factors. In the Trap-area, one of the

important factors controlling underground water (*i.e.* the geological formation) shows a uniformity of character over more or less a wide area. On this account, a good part of the story of the distribution of underground water becomes intelligible when systematic work has been carried out in the area. Other contributory causes, some of them equally or more important, such as rainfall, physiographic peculiarities have also a great influence on the sub-surface water. When a layer is described as an aquifer, it is meant to convey, that on account of its special physical characters, that layer is capable of retaining and yielding much more water, comparatively, than other layers in that locality.

In conclusion, I have much pleasure in acknowledging my grateful thanks to the Special Officer for his helpful suggestions during this work.

Lingsugur
7/12/1932.

C. Mahadevan.
Asst Supt. Hyderabad Geological Survey

NOTE BY THE SPECIAL OFFICER I/C, GEOLOGICAL SURVEY DEPARTMENT.

In the absence of sufficient data, Dr. Mahadevan has rightly omitted any reference to water under pressure having been struck near Sholapur, at Mr. Desai's garden well at Barsi, and a well belonging to Nanchand Guzur, about 3 miles north of Parenda. I myself can at the moment give no solution to these anomalous conditions in apparently horizontal strata, unless the bore-holes have met fissures, which connect with stored water, such as the Sholapur and Barsi tanks, lying on higher ground. This undoubtedly explains the sub-artesian condition met with when a bore was drilled at the bottom of Gunj Well at Latur, as unless the tank is full, the bore-hole does not function. However, such a condition will not account for water under pressure in the Nanchand Guzur's well in the Parenda-Bhum lava zone. If the existence of some layer in which water under pressure could be consistently struck was proved it would make not only a great difference to the agricultural prospects of the famine zones, but entirely revolutionize our ideas as to how permanent village drinking water supplies are to be arranged. For this reason I most strongly recommend Government to supply a fully equipped core-drill to the Geological Survey Department to test this most intriguing question. The drill could also prove the existence and nature of aquifers in areas where natural sections are not available.

L. MUNN.

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B.